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TELEPHONY

A DETAILED EXPOSITION OF THE TELEPHONE EXCHANGE SYSTEMS OF THE BRITISH POST OFFICE

BY

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TELEPHONY

HERBERT & PROCTER

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FOREWORD

TELECOMMUNICATIONS practice, like most other branches of applied electrical science, has advanced with great strides during the past few decades. The appearance of this new and up-to-date edition of *Telephony* is, in consequence, a welcome event to all telephone men and is a valuable addition to existing literature on the British telephone system. In conformity with the earlier editions, the book is intended primarily for those engaged on the installation and maintenance of telephone exchange equipment and the associated subscribers' apparatus.

In dealing with a subject so broad as Telecommunications, it is almost impossible to publish a work which entirely covers all phases and, in his treatment of Telephone Exchange Systems, the author has dealt with this phase in a manner that should appeal alike to the beginner and the more advanced student. He has, wisely, left the study of basic electrical theory and principles to be pursued elsewhere. The omission of External Plant Practice and Transmission may be questioned in some quarters, but there is no shadow of doubt that with the prevailing high degree of specialization, those phases of the art call for separate treatment.

This publication has been written by an author who has a wide experience of the subject and should appeal to all engaged in the art.

C. W. BROWN
Staff Engineer, Telephone Branch,
Engineer-in-Chief's Office
G.P.O.

London,
September, 1947.

PREFACE

Some years have now passed since I was first approached by Mr. T. E. Herbert to co-operate with him in the preparation of a new edition of his *Telephony*. For various reasons, very little progress had been made when the outbreak of hostilities in 1939 necessitated the complete suspension of work on the new edition. The sudden and lamentable death of Mr. Herbert early in 1943 finally prevented the fulfilment of the original plans and the onus of preparing a new textbook fell upon my shoulders. It has been my earnest endeavour to make the new *Telephony* a worthy successor to the earlier editions prepared by the late Mr. Herbert and Mr. Procter.

Modern telephone practice involves the application of a wide range of basic electrical and electromagnetic principles which cannot be adequately considered in a book devoted primarily to Telephony. There are a number of excellent textbooks on electrotechnology and I have therefore made no attempt to explain the fundamental electrical principles, but have assumed that the reader already possesses a working knowledge of elementary direct current and alternating current theory. External line plant together with the theory and practice of telephone transmission have also developed into highly specialized subjects and have been omitted in order to allow of a more comprehensive treatment of telephone exchange systems and allied subjects.

This new edition is primarily devoted to the signalling and switching aspects of telephony. Even so, the complexities of modern telephone exchange systems are so extensive that it has been found necessary to divide the work into two volumes, viz:

Volume I. General principles and manual exchange systems.

Volume II. Automatic exchange systems.

At the time of writing this preface, Volume II is in course of preparation. The two volumes together have been designed to cover Grades I, II, and III of the new City and Guilds examinations in *Telephone Exchange Systems* and the telephone aspects of *Elementary Telecommunications Practice*. (See Appendix I.)

The circuits of telephony are becoming more and more complex and new circuits are being added almost daily. It is therefore of increasing importance that the student should concentrate on the fundamental circuit elements rather than attempt to understand the practical details of complete circuits. On the other hand, a book on telephony is not, in my opinion, complete unless it also shows how the various common elements are applied to practical circuit design. I have attempted, in so far as space will permit, to examine the principles and circuit elements which are common to telephone switching in general, and to give a representative selection of typical complete circuits. The treatment is perhaps somewhat unorthodox in that I have dissociated the various signalling, transmission, and switching principles from the exchange systems to which they are normally applied. By this means, it is possible to compare more effectively the merits, limitations, and field of application of each method and, at the same time, to obtain a better overall picture of each specific problem.

Some thirteen of the first nineteen chapters in this volume deal with principles rather than with complete circuits. Chapter I covers in some detail those aspects of sound and speech which are necessary to obtain a firm basis for the study of telephony. Chapter II introduces the language of diagrams and offers suggestions to facilitate the examination of telephone circuits. Chapters III and IV describe the principles and design of certain common components such as transmitters, receivers, transformers, etc., and lead to the consideration of the transmission features of telephone circuits in Chapter V. Similarly, two chapters are devoted to relays and other signalling apparatus prior to an examination of local line signalling in Chapter VIII. Chapter IX co-ordinates the transmission and signalling elements and describes the practical design of subscribers' telephone apparatus. Chapter X deals with the principles involved in the design of a manual switching system and provides the basis for the consideration of private branch switchboards in Chapter XI. Chapter XII introduces the various methods of routing calls between exchanges and provides an introduction to the principles of junction and trunk line signalling in Chapter XIII. Chapter XIV deals with items such as protection, cabling, mounting of apparatus, etc., which are common to exchanges of all types. Finally, Chapters XV to XIX show the application of the principles already considered to specific manual exchange systems. It will be noted that one chapter (No. XV) describes the now obsolescent Magneto and C.B.S. systems. There are still a number of such

exchanges in service and a description of the main circuits provides a valuable stopping stone to the more complex arrangements of modern systems. Moreover, the junction circuits between magneto and C.B.S. exchanges and the more modern C.B. and automatic systems present some interesting and current problems to the telephone engineer in the field. Particular stress has been placed on this aspect of the older systems.

The two final chapters have been devoted to telephone exchange power plant and the principles and methods of testing.

I trust that readers will favour the larger page size of the new edition which has been adopted in order to facilitate the reproduction of the larger diagrams and to enable the descriptive matter to be more closely associated with the appropriate illustrations. I also hope that the selection of questions at the end of each chapter will be of value to students who are desirous of taking the City and Guilds examinations.

In conclusion, I would like to place on record my gratitude and deep obligation to Col. Sir A. Stanley Angwin, K.B.E., D.S.O., M.C., T.D., M.I.E.E., Engineer-in-Chief of the Post Office, for his permission to use official information, diagrams, etc. Without these facilities it would, of course, have been impossible for the present work to have been produced. I would also like to tender my grateful thanks and appreciation to my numerous friends both in the Post Office and in the telephone manufacturers' organizations who have generously assisted in various ways. I am, in particular, indebted to Mr. C. W. Brown and Dr. L. E. Ryall for their interest and advice, to Mr. F. W. Dopson and Mr. G. Howard who have prepared the illustrations, and to Miss H. N. McLellan for her assistance with the manuscript.

I am pleased to acknowledge my obligation to the following firms, who have supplied illustrations or special information relating to the apparatus which they manufacture:

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I would also like to express my thanks to:

Mr. W. S. Procter for his permission to utilize material and illustrations from *Telephony*, Vol. I (1932 edition), and *Telephony*, Vol. II (1938 edition).

The Board of Editors of *The Post Office Electrical Engineers' Journal* for the loan of blocks.

The National Physical Laboratory and Dr. E. G. Richardson of Durham University for material on Sound and Speech.

Messrs. Macmillan & Co. Ltd. for permission to reproduce information from *Speech and Hearing* by Harvey Fletcher.

Mr. N. V. Knight for permission to use several illustrations from *Poole's Telephone Handbook*.

The City and Guilds of London Institute for permission to reproduce extracts from the examination syllabuses and past examination papers.

Whilst every care has been taken to ensure accuracy, it is possible that some errors or inaccuracies may have escaped detection. I should therefore be grateful if any reader who finds any such error will favour me with an advice under cover to the publishers.

J. A.

Edinburgh,
October, 1947.

CONTENTS

TELEPHONY

GENERAL PRINCIPLES AND MANUAL EXCHANGE SYSTEMS

CHAPTER I

SOUND AND SPEECH

THE history of communications is as old as that of man himself for, from the earliest records, there is evidence of man's desire and efforts to communicate speedily with others beyond the range of human voice and sight. Probably the first method of communication was by means of runners and, even in comparatively recent centuries, fires or beacons were commonly employed as a means of rapid communication. One can, in fact, quote innumerable methods, such as drums, semaphore, and so on, which have been used successfully at various times for the rapid transmission of information. All of these methods of communication were essentially *telegraphic*, i.e. they involved the transmission of a written message or the use of oral or visual coded signals.

It was not until the nineteenth century that physicists turned seriously to the scientific examination of speech sounds. This, together with the historic pioneer work of Oersted, Davy, Sturgeon, Faraday, Page, and many others in the electrical field paved the way to Graham Bell's electric telephone of 1875. The word telephone (which incidentally is derived from the two Greek words *tele*, meaning at a distance, and *phone*, meaning speech) was in use some considerable time before Bell's patents, and was—according to some authorities—first used by Sir Charles Wheatstone to describe a mechanical arrangement which he had devised to transmit speech from one room to another. In modern usage the true literal derivation is somewhat lost, and the word *telephone* almost invariably implies the transmission of speech over a distance by means of electric currents.

It is highly desirable to commence the study of telephony with a proper understanding of the nature and behaviour of sound, and particularly the form of sound with which telephony is most concerned, i.e. human speech. All who possess the normal faculty of hearing are fully aware of the diversity of the sounds which form a part of everyday life. Some sounds are irritating to a greater or lesser degree, whilst others are pleasing or even musical. Moreover, sounds can be further described by such terms as *loud, soft, harsh, mellow, explosive, high pitched, low pitched*, and so on. What then, is the nature of this sound which excites the auditory system in so many different ways?

The Source of Sound. When any source of sound, such as a tuning fork, bell, or violin string is examined, it is found that the emitting body is in a state of mechanical vibration. In some cases this vibration is apparent to the naked eye by the blurred outline. Less pronounced and more rapid vibrations can be detected by means of a pith ball, whereas other vibrations may require sensitive apparatus for their detection. In every instance, a sound can be traced to the mechanical vibration of some solid, fluid, or even, as in the case of organ pipes, to the vibration of a column of air.

The Medium of Propagation of Sound. The propagation of sound from a vibrating body to the ear requires the presence of some conducting medium between the two. That this medium is material may be shown by the simple experiment of supporting an electric trembler bell by means of fine flexible wires in a glass jar from which the air can be exhausted. With the glass jar full of air at normal atmospheric pressure, the hammer striking the bell gong can be both seen and heard. As the air is exhausted, the sound gradually fades away, although the continuous ringing of the bell is apparent from the visible vibration of the hammer. If the pumping system will allow the air pressure to be reduced to a value approaching a vacuum, the sound ultimately disappears, but the readmission of air into the jar once again enables the sound to be heard. Hence, it may be inferred that air conducts sound, but that a vacuum does not. Moreover, the volume of a sound propagated through air is largely influenced by the *density* of the air through which it travels.

Further experiments with the same apparatus will show that sound is conducted to varying degrees by any other gas or vapour, and, in fact, by all solids and fluids. Unlike light, which passes readily through the ether of space, sound requires

some molecular medium for its transmission. In everyday life and in most of the problems of telephony, air is the conducting medium of sound, and the considerations of this chapter are therefore largely restricted to the propagation of sound in air.

Sound Waves. The nature of sound and its method of propagation can perhaps best be illustrated by means of a mechanical analogy. Visualize (Fig. 1) a series of small weights $W1$ to $W8$ suspended at equal intervals from the ceiling of a room and connected together by means of helical springs $S1$ to $S8$. An arrangement is provided whereby $W1$ can be oscillated by means of a crank system coupled to an electric motor via a worm reduction gear. When $W1$ is made to oscillate from left to right in a regular periodic manner, it will alternately compress and expand spring $S1$. Changes in the tension of $S1$ produce corresponding forces at its right-hand fixing $W2$, and the latter, which is itself free to move, will oscillate in a similar manner to $W1$. Movement of $W2$ in turn produces expansive and compressive forces in $S2$, and the process is continued along the line of weights until the whole row is in a state of oscillation. It would be noted from this experiment that an appreciable time is taken for a wave of compression or expansion to travel along the line of springs and weights. A moment's thought will reveal that this time is dependent upon the *mass* of the weights (which determines their inertia) and upon the *elasticity* of the springs. Very heavy weights, in conjunction with light springs, will produce a long transit time, whilst, conversely, light weights and stiff springs will give a rapid transmission of motion.

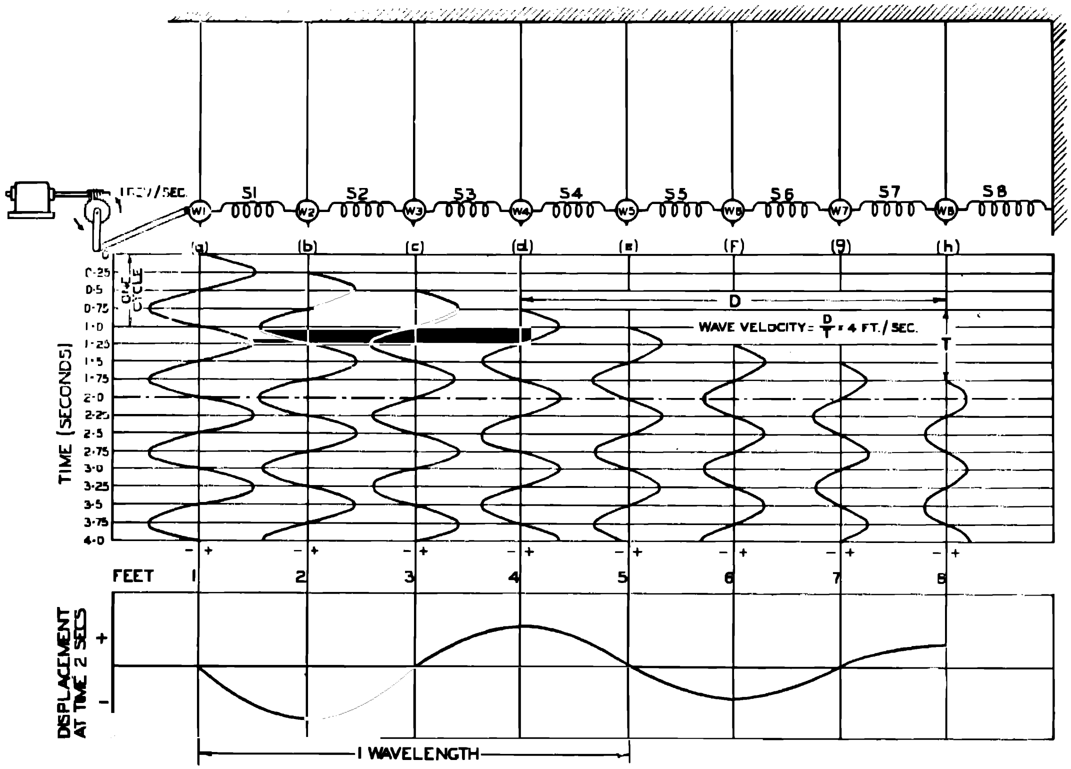
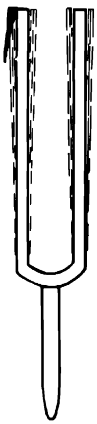


FIG. 1. MECHANICAL APPARATUS TO ILLUSTRATE THE WAVE-MOTION OF SOUND

The weights and springs of this experiment are analogous to a row of molecules in any elastic medium, such as air, and the movements of the molecules under the action of sound pressure are identical to those of the weights (Fig. 2). The analogy may be taken still further, for, whilst the mass of the weights and the elasticity of the springs determine the wave velocity in this experiment, the density and elasticity of any medium decide the velocity of a sound wave through it. There are many examples of this type of wave motion, such as, for instance, the effect on the wagons of a shunting train when the engine

oscillates backwards and forwards. A further example is the wave of compression which occurs in a mass of people when a sudden momentary pressure is applied at the rear of the crowd. The transmission of sound is a wave motion of air pressure (hence the term *sound wave*), and it is the rapid variation of air pressure in contact with the ear which produces the sensation of sound, the pitch and character of the sound depending on the frequency and manner of the variation.

It is important to realize that, during the transmission of sound waves in air, the molecules of air do not move bodily away from the source, but merely oscillate about their normal position, passing on some of the energy of their movement to the adjacent particles. A sound wave is transmitted by the movement of particles which oscillate in the same direction as the movement of the wave. It is for this reason that a sound wave is called a *longitudinal wave* to distinguish from a *transverse wave*, which describes a wave motion where the movement of the particles is at right angles to the movement of the wave. The waves on the surface of water and the wave motion of light are examples of this latter type.



Sine Waves. Reverting to the apparatus of Fig. 1, it will be seen that when the motor is run at constant speed, the movement of $W1$ is identical with that of a simple pendulum. Since the speed of the motor is constant, the time taken for one complete oscillation of $W1$ is also constant. Moreover, the amplitude of each succeeding oscillation is the same, and if a pen were attached to the weight and adjusted to mark a strip of paper passing under it at constant velocity, the resultant curve would be as shown at (*a*). The motion of $W1$, like that of a free pendulum, is the simplest form of oscillatory movement, and is known as *simple harmonic motion* (abbreviated S.H.M.). The amplitude of the curve is at all times proportional to the sine of the angle through which the crank is rotated from its normal position, and hence this trace is known as a *sine curve*. Parts of the curve to the right of the axis represent a compressive displacement of the springs, and those to the left of the axis refer to displacement in an expansive direction. It is sometimes convenient to designate these displacements as positive (+) and negative (−) respectively.

Each complete oscillation (i.e. the movement due to one complete revolution of the driving crank) is termed a *cycle*, and the number of such cycles occurring in unit time is known as the *frequency*, which is usually expressed in cycles per second (c/s). In Fig. 1, the frequency of the wave is 1 c/s.

Wave Velocity. If the pressure on the springs is proportional to their degree of compression, the pressure wave passing along the line will also vary in accordance with a sine curve. The maximum compression of successive springs will, however, occur at different instants due to the transit time of the wave. Curves (*b*), (*c*), (*d*), etc., illustrate this transit time and are drawn to indicate a wave velocity of 4 ft per sec. It has already been stated that the speed of the wave is dependent upon the

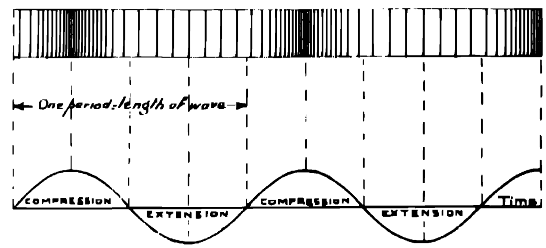


FIG. 2. SOUND WAVES PRODUCED BY A TUNING FORK

mass of the weights and the elasticity of the springs, and that the propagation of a sound wave is similiary dependent on the elasticity and density of the medium through which it travels. Newton first calculated the velocities of sound waves in various media and established the general relationship—

$$\text{Wave velocity} = \sqrt{\frac{\text{elasticity of medium}}{\text{density of medium}}}$$

Numerous classical experiments have verified that a velocity of about 33 200 cm/sec (1088 ft/sec) is the normal speed of sound in air—although the atmospheric pressure, humidity, and temperature have an appreciable influence on the velocity. The corresponding velocity of sound in water is about 150 000 cm/sec, whilst in metals the velocity is in the order of 400 000 cm/sec. The velocity of sound in any medium is, however, very much less than that of light, which has a velocity of some 3×10^{10} cm/sec. The flash and report of a lightning discharge occur simultaneously, but the flash reaches the earth's surface some seconds before the corresponding thunder. The time lag is usually so great that it can be measured easily with an ordinary watch, and the distance of the discharge is readily calculated from a knowledge of the relative velocities of sound and light.

Wavelength. If in the apparatus of Fig. 1 there

are a sufficient number of weights, it will be noted that, at regular intervals along the line, certain weights are oscillating exactly in synchronism with the first weight. A further examination of the displacement of the weights between any two of these points will show that *at any one instant* a sine wave cycle of displacement exists. In Fig. 1 the instantaneous values of displacement at time 2 sec are measured for each weight along the line. These values are plotted on a distance base in the lower part of the illustration and show clearly the sinusoidal pressure wave along the line of springs at that instant. From this lower curve it is possible to measure the distance apart of any two points such that there is a phase difference of exactly one complete cycle. This distance is known as the *wavelength*.

Unlike the velocity (which is determined wholly by the physical characteristics of the medium of propagation) the wavelength is dependent jointly on the medium and on the frequency of the wave. Thus, for any wave:

If the frequency	$= f$ c/s
the time taken for one complete cycle	$= 1/f$ sec
If the velocity of propagation	$= v$ cm/sec
then the distance travelled in 1 sec	$= v$ cm
and the distance travelled in $1/f$ sec	$= v/f$ cm.

Hence, the first cycle will have travelled a distance of v/f cm when the second cycle is just commencing at the source, i.e.

$$\text{Wavelength} = \lambda = v/f.$$

Thus, a sound of 1000 c/s travelling in air where the wave velocity is 33 200 cm/sec has a wavelength of 33·2 cm, or 13 in. approximately. Similarly, waves of 3000 c/s and 100 c/s would, in the same medium, have approximate wavelengths of 11·1 cm and 332 cm respectively.

Frequency and Pitch. The frequency of any particular sound wave indicates to the human auditory system the *pitch* of that sound. A low-frequency wave is translated as a low-pitched note and conversely a higher frequency wave gives a note of higher pitch. Strictly speaking, longitudinal waves may only be classified as sound waves if their frequency falls within the range of sensitivity of the human ear. A body vibrating at, say, 10 or 30 000 c/s would produce waves which are identical in character to sound waves but which are inaudible to the normal ear. Such waves are of no concern in this chapter, although the waves above the audible range (often known as *supersonic waves*) are becoming increasingly used for such purposes as depth sounding for ships and the testing of materials, etc.

Pitch is applicable to musical notes rather than to indeterminate noises and, from the very earliest of days, certain intervals or changes of pitch were recognized. The octave—which Pythagoras showed was a frequency ratio of 2 : 1—was one of the first known musical intervals, since it was found that two instruments or voices producing notes differing by one octave in pitch gave a pleasing effect when played in unison. Later, the musical intervals of a fifth, fourth, major third (corresponding to frequency ratios of 3 : 2, 4 : 3, and 5 : 4 respectively), etc., were introduced into musical theory. Adjacent notes on a piano or other keyboard instrument represent the smallest intervals which it is possible to obtain on that instrument, but it is important to realize that in this and in all other musical instruments equal intervals are the result of equal *ratios* of frequencies and not of equal increments of frequency. This important principle can be readily demonstrated by arranging, say, five toothed wheels having respectively 5, 10, 20, 40, and 80 teeth per wheel on the shaft of an electric motor. When a card is held lightly against the teeth of the rotating wheels a musical note is emitted, the pitch being determined by the number of vibrations per second. By moving the card from one wheel to the adjacent wheel it would be found that equal intervals of pitch are produced by equal ratios of vibrations. It is not unnatural that the ear should associate notes by the ratio of the frequencies since, as will be seen later, the natural vibration of any body is accompanied by overtones or harmonics which are simple multiples of the fundamental frequency.

In Fig. 3 the approximate frequency ranges of the human voice and of a number of the more common musical instruments are compared with that of a piano. The range given for each instrument takes into consideration only the *fundamental* or basic notes obtainable, but does not show the harmonics of these notes which are largely governed by the design of the instrument and have a frequency spectrum extending considerably higher than the fundamentals.

In general—and ignoring percussion instruments such as triangles, cymbals, etc.—the musical range extends from the 32 c/s note represented by the bottom C of a piano to the top A of the same instrument which has a fundamental frequency of 3413 c/s. The human singing voice has a much smaller range and extends from a frequency of about 75 c/s for the lowest note of a bass voice to about 1000 c/s for the top note of a soprano. The

normal speaking voice ranges from approximately 75 c/s for males to approximately 300 c/s for females. Whilst it is interesting to know these fundamental frequencies, it should at the same time be understood that it is the higher frequency *harmonics* which, as will be seen later, determine characteristics of an instrument and which form the chief problem in electrical transmission.

continuous note of an organ pipe is only maintained by the application of a continuous stream of air to the lip or reed of the pipe. In other musical instruments, the tonal quality is largely dependent upon the rapid decrement or *damping* as it is termed; and in the piano, for instance, the mechanism is arranged to apply a pad of felt to the string as the key is released.

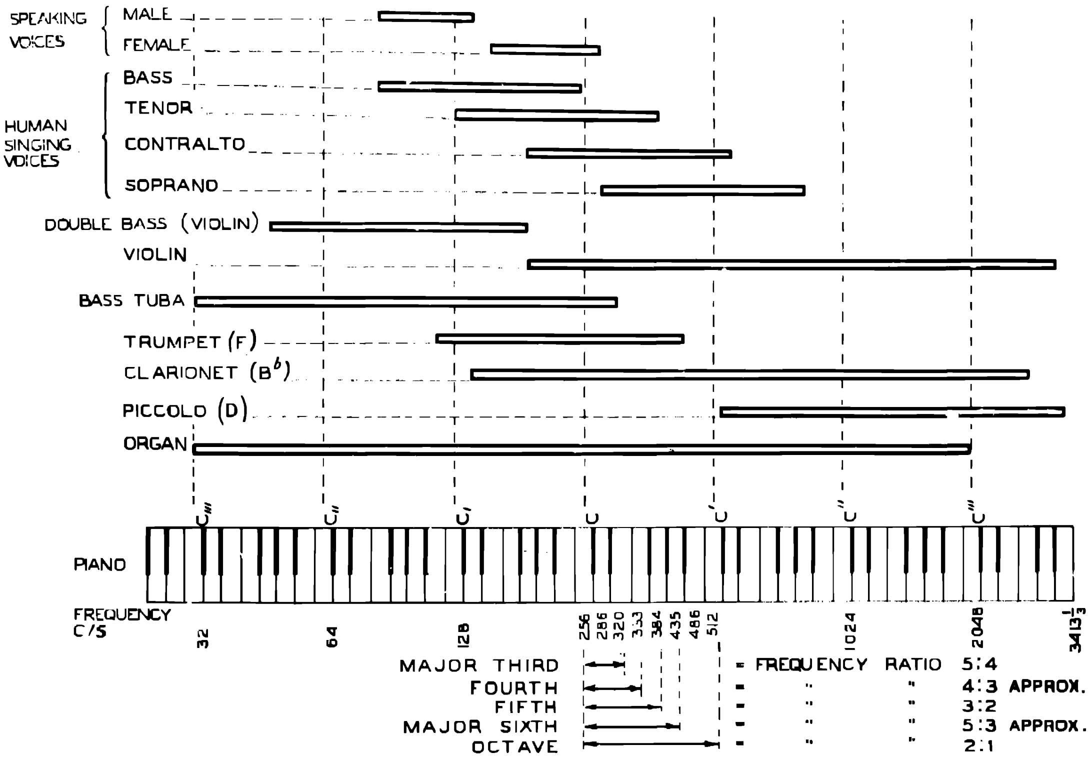


FIG. 3. FUNDAMENTAL FREQUENCY RANGE OF TYPICAL INSTRUMENTS AND VOICES

Volume and Attenuation. As is to be expected, the volume of a sound is determined by the *amplitude* of the air pressure wave—the amplitude in turn depending upon the extent of the mechanical vibration causing it. Any vibrating body must expend energy in overcoming the forces within it and in imparting to the surrounding air the molecular movements of a sound wave. Unless this loss of energy is replaced, the vibrations die away and so do the corresponding sound waves. Thus, the volume of sound emitted by a tuning fork gradually decays as the vibration of the prongs dies down, and if a continuous sound of constant volume is required, it is necessary to provide a means of imparting to the fork energy at the same rate as the loss of energy. In a similar manner, the

Apart from the decrease of intensity of a sound at the source, any sound wave decreases in magnitude as it moves away from the source. This diminution of intensity or *attenuation* is due partly to the transfer of the kinetic energy of the wave into heat energy in the medium (as a result of the work done by the molecules against the forces of viscosity); and partly due to the divergence of the wave over a greater area as it proceeds from the source. This latter factor can be appreciated if we consider a point source of sound which produces a total sound energy output of, say, E ergs per sec. This sound energy is distributed evenly throughout the space surrounding the source, and if we imagine a sphere of 1 cm radius with the source at its centre, the intensity of sound energy on each

square centimetre of the sphere's surface is the total energy divided by the surface area of the sphere, i.e. $E/4\pi r^2 = E/4\pi$. If now it is assumed that the radius of the sphere is 2 cm, the sound energy on each square centimetre becomes $E/16\pi$ and, again, if we consider a sphere of 3 cm radius the value becomes $E/36\pi$. Thus, the sound energy per unit area decreases to one-quarter when the distance from the source is doubled, and to one-ninth when the distance from the source is trebled. This is the *inverse square law* so well known in connexion with light intensity, and although it is strictly only applicable when the source of sound is a point, it is nevertheless fairly true for most practical conditions. It is interesting to note that a number of instruments such as the ear trumpet, speaking tube, etc., are designed expressly to improve transmission by the limitation of the wave divergence.

In acoustics, as in all other scientific studies, it is necessary to have an agreed and universally understood unit for the measurement of sound intensity. Probably the simplest method of assessing the magnitude of a sound wave at a given point is to measure the actual pressure exerted per unit area at that point. It is convenient to use the C.G.S. system of notation, and a sound pressure of 1 dyne per sq cm is therefore the basic unit. The sound pressure referred to is, of course, the alternating pressure due to the sound wave alone, and does not take into consideration the static atmospheric pressure of the air which, being constant, does not affect the auditory system. Moreover, the alternating sound pressure varies from instant to instant, and it would be inaccurate to compare the energies of two waves by measuring their peak values of pressure owing to possible differences in the shape of the two waves. As in alternating current engineering, sound measuring instruments are calibrated to read the *root mean square* (r.m.s.) value of pressure. The r.m.s. value gives a true measure of the energy of a wave irrespective of wave shape and for a pure sinusoidal wave is $1/\sqrt{2}$ of the maximum value.

Whilst the "dyne per sq cm" fulfils all requirements for an absolute measurement of the magnitude of a sound wave, it is nevertheless of little value as an indication of *relative* volumes as translated by the ear. If, for instance, a sound of 10 dynes per sq cm is increased to 20 dynes per sq cm, the sensation of intensity is by no means doubled. Similarly, if the same sound is further increased to 30 dynes per sq cm the increase in intensity to the ear is not so great as the first step of 10 dynes per sq cm. Except at extremes of frequency and intensity the ear does, in fact, register equal increases of loudness when the sound pressures increase by the same *ratio*. Thus, sound pressures of 10, 20, and 40 dynes per sq cm form a geometrical progression with a common factor of two, and hence there will be the same apparent increase in volume between 10 and 20 dynes per sq cm as between 20 and 40 dynes per sq cm. This characteristic of the auditory system can if desired be verified by means of an oscillator, amplifier, and loud speaker. The oscillator should be adjusted to give a steady tone of say, 800 c/s and the circuit arranged so that two different powers of the same tone can be connected alternately to the loud speaker. Commencing with a low value, the strength of each tone is adjusted to produce equal volumes when a change-over key is operated. One tone is then increased until, when the key is thrown, there is just a perceptible difference in the two tones. The power applied to the loudspeaker is noted and the lower tone is increased until it is just louder than the other tone. The power is read again and the experiment is continued, first raising one tone and then the other, each increase being that necessary to produce the minimum noticeable difference in volume. On comparing the relative powers it will be found that, provided the volume is not excessively low or high, the ratio to produce the same apparent minimum increase in volume is the same at each step. With normal persons and with sounds of medium frequency and intensity, the ratio is in the order of 3/2, and this ratio might be called a unit of difference in volume. On this basis two sounds having power ratios of 9/4 would have a difference of volume of twice the minimum perceptible amount, but it becomes an involved calculation to find the difference in volume of two sounds having, say, a power ratio of 5 : 1. The ratio $5/1 = 80/16 = (3/2) \times (3/2) \times (3/2) \times (3/2)$ approx., i.e. there is roughly four times the unit difference in volume—a fact not at all apparent from the power ratio.

The Decibel. In order to avoid the cumbersome process of *multiplying* power ratios in order to *add* differences of volume, a logarithmic unit known as the *bel* has been adopted as standard. The bel, which is equally applicable to electrical, acoustical, or any other form of energy, may be defined as the common logarithm (i.e. to base 10) of the ratio of two powers. Thus:

$$\text{No. of bels} = N = \log_{10} \frac{P_1}{P_2}$$

where P_1 and P_2 are the powers,

or
$$\text{Power ratio} = \frac{P_1}{P_2} = 10^N.$$

The bel, representing as it does a power ratio of

10 : 1, is too large for most purposes and a subunit, the *decibel* (abbreviated db), which is one-tenth of a bel, is almost universally used in communication and acoustical engineering. From the definition:

$$\text{No. of decibels} = n = 10N = 10 \log_{10} \frac{P_1}{P_2}$$

$$\text{or power ratio} = \frac{P_1}{P_2} = 10^{n/10}$$

It has already been stated that the minimum perceptible difference in the volume of two sounds occurs when they have a power ratio of approximately 3/2. A change of 1 db represents a power ratio of 1·259 or 5/4 approx., and 2 db is a ratio of 25/16 = 3/2 approx. Hence it can be said that the ear will just detect a difference in volume when the power varies by two decibels. This statement, whilst approximately true for normal frequencies and intensities, does not, however, apply for extremes of frequency or for very low intensities, and a change of four or more decibels may be necessary under such conditions to produce a noticeable change in volume.

The decibel is used not only to compare the relative powers of two separate sources, but also to state the amount of attenuation of power from a given source at different points. If, for instance, between successive points *A*, *B*, *C*, and *D* (Fig. 4) a sound wave attenuates 3 db between *A* and *B*, 1 db between *B* and *C*, and 10 db between *C* and *D*, the total attenuation is the algebraic sum of the individual attenuations, i.e. 3 + 1 + 10 = 14 db. If such attenuations were considered from the actual power ratios, the total attenuation would be a powers ratio of 2/1 × 5/4 × 10/1 = 25/1—a result which, whilst of value for theoretical calculations, does not give a satisfactory impression of the actual decrease in volume between *A* and *D*.

It has been stated that the bel and the decibel are essentially the logarithmic ratios of two powers. In an electrical system the power is a function of the voltage (E) and the impedance of the circuit. If the impedance of the circuit is constant then the power available at any point in the circuit is directly proportional to the voltage squared (E^2). Similarly, the energy of a sound wave is dependent upon the velocity of the wave and its pressure (p). In a homogeneous medium, the velocity of a sound wave is constant, and the energy of the sound at any point is proportional to the square of the pressure (p^2). Thus (with a constant velocity) the number of decibels between a wave of p_1 dynes per sq cm, and a similar wave of p_2 dynes per sq cm is given by:

$$\begin{aligned}\text{Attenuation (db)} &= 10 \log_{10} \times \text{(power ratio)} \\ &= 10 \log_{10} \times \text{(square of pressure ratio)} \\ &= 20 \log_{10} \frac{p_1}{p_2}\end{aligned}$$

If a wave passing through a homogeneous medium has, for instance, pressures of 100 dynes/sq cm and

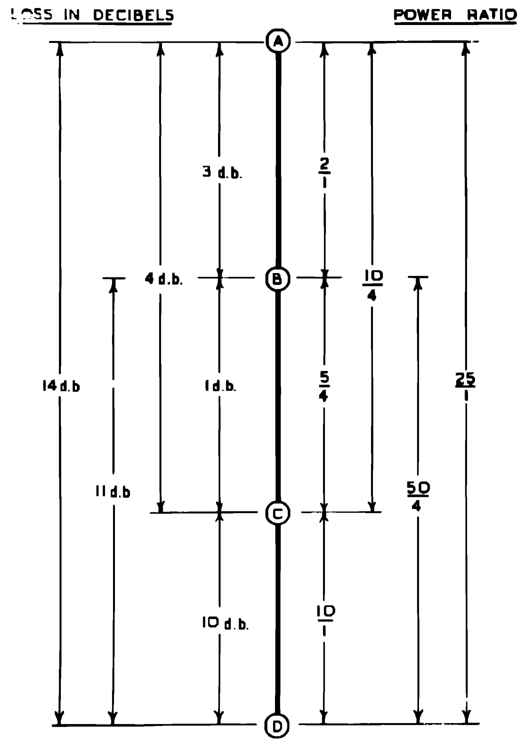


Fig. 4. Comparison of Decibel and Power-ratio Notations

1 dyne/sq cm at successive points x and y, the attenuation between these points is given by:

$$\text{Attenuation (db)} = 20 \log \frac{p_x}{p_y} = 20 \log \frac{100}{1} = 20 \times 2 = 40 \text{ db.}$$

To the communication engineer, the decibel as a unit of attenuation is perhaps more associated with electrical powers than with the actual speech energy. Occasional references will be found in the following chapters to the loss in decibels of certain apparatus, and particular stress has been placed on this unit in the present chapter on account of its application to electrical attenuations. To some students of telephony, there is difficulty in grasping the real significance or the magnitude of the decibel.

To those students, it may be of assistance if it is remembered that:

1 db = a power ratio of 5/4 (approx.)
3 db = a power ratio of 2/1 (approx.)
10 db = a power ratio of 10/1
20 db = a power ratio of 100/1

If these values are firmly impressed on the mind, it is possible to visualize the power ratio represented by any number of decibels by the mental multiplication of selections of the above. To illustrate, a loss of 17 db may be considered as additive losses

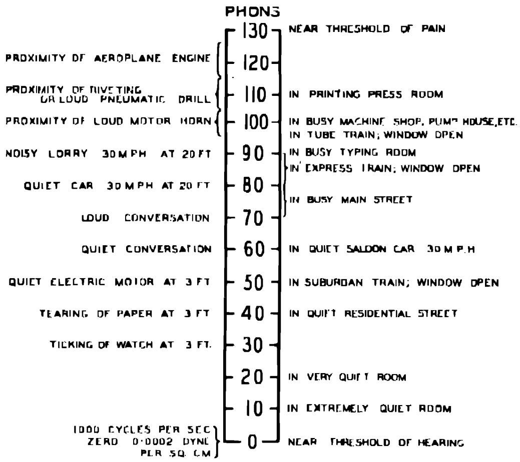


FIG. 5. APPROXIMATE LOUDNESS LEVELS OF TYPICAL NOISES

of 10, 3, 3, and 1 db, and hence the power ratio is (10/1) × (2/1) × (2/1) × (5/4) = 50/1. Alternatively loss of 17 db can be considered as a loss of 20 db plus a gain of 3 db, i.e. the power ratio is

$$(100/1) \div (2/1) = 50/1.$$

The Phon. Whilst the decibel fulfils all practical requirements for the comparison of the *relative* magnitudes of two sound levels, it does not, however, give any indication of the absolute strength of a sound. This latter requirement has necessitated the introduction of a further term which combines the decibel notation with an agreed minimum sound intensity. The unit is the *phon*, and a sound is said to have an intensity of one phon if it is one decibel above the minimum perceptible level of sound. The minimum perceptible sound, or *threshold*, varies not only with the individual but also with the frequency of the sound, and hence an arbitrary threshold of 0·0002 dyne/sq cm at 1000 c/s has been agreed internationally (International Acoustical Conference, Paris, 1937). A sound of 100 phons is therefore equal in intensity to a 1000-cycle note 100 db above a sound pressure of 0·0002 dyne/sq cm (i.e. equal to a 1000-cycle note of 20 dynes/sq cm). As will be appreciated, some difficulties occur in comparing with the specified 1000 c/s tone, a sound which may consist of a mixture of frequencies, and in order to minimize any discrepancies a rigid testing procedure is laid down by the British Standards Institution and by similar bodies abroad. Whilst the phon has a limited field of application in telephony, it is proving of great value in the study of street and other noises, the abatement of which is occupying so much attention at the present time. Fig. 5, which is based on figures supplied by the National Physical Laboratory, gives the relative intensity of the noise in a number of familiar situations.

Harmonics or Overtones. So far only sound waves having a sinusoidal form and emanating from a body vibrating with simple harmonic motion have been considered. Such simple vibrations are comparatively rare owing to the fact that most bodies when set into oscillation not only vibrate as a whole but also in various parts. This phenomenon can readily be demonstrated by means of a tightly stretched string attached to a sounding board in the manner of a violin string. If the string is bowed or plucked it will appear to vibrate as a whole at a frequency determined by the tautness, length, and mass of the string. It is apparent that the maximum movement of the string occurs at the centre, and if the fundamental vibration is damped out by touching the string lightly at the centre, it will be found that each half of the string vibrates independently at a frequency which is double (i.e. one octave higher) that of the fundamental. Similarly, if the second harmonic vibrations are also damped out by touching the string at one-quarter of the length from the end, each quarter of the string will vibrate at a frequency four times that of the fundamental. The experiment can be repeated by damping at one-third of the length, and so on. All these *harmonics* or *overtones* must have been present when the string was first plucked, but they are normally masked by the larger vibrations of the fundamental note.

All musical notes consist of a fundamental frequency on which are superposed overtones or harmonics which are whole multiples of the fundamental. The harmonics may be of any magnitude, although, generally, they are less than the fundamental. Moreover, they can have any phase relationship with one another. To the communication engineer harmonics of two, three, four, etc., times the frequency of the fundamental are known respectively as the second, third, fourth, and so on harmonics of that fundamental; but, unfortunately, the musician often refers to these harmonics as

the first, second, third, and so forth, and there is sometimes a tendency to confusion as a result of this anomaly. The human voice, like all musical notes, is rich in harmonics and the resultant wave forms are all more or less complicated. The

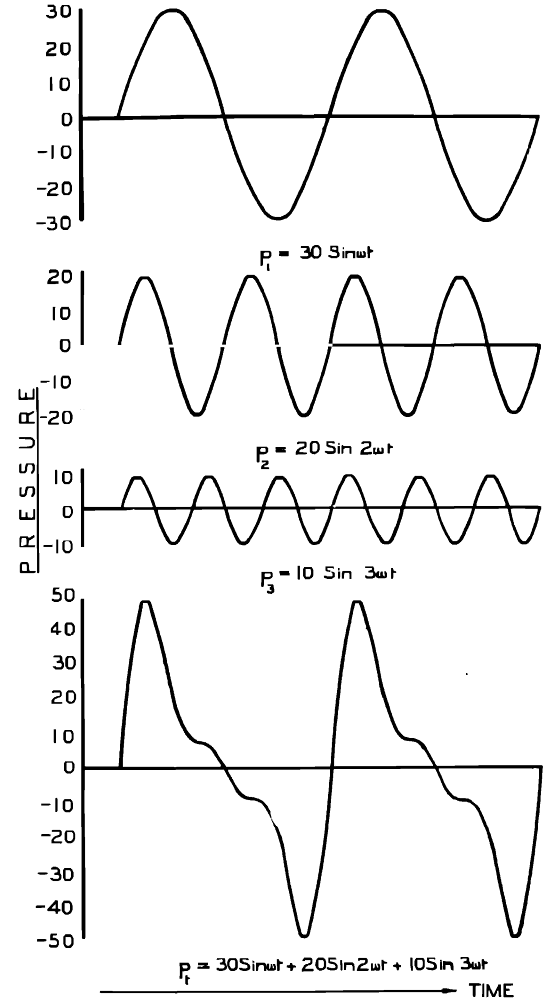


Fig. 6. Complex Wave Resulting from the Combination of Three Sinusoidal Waves

harmonic contents of any note, together with the degree of damping, determine the tonal quality or *timbre* of the note. It is important, therefore, that if *naturalness* is required in any transmission system the higher frequency harmonics must be faithfully reproduced.

Complex Waves. All wave forms other than simple sine waves are known as *complex waves*. It can be shown either by direct graphical analysis or alternatively mathematically by the application of Fourier's theorem that any complex wave, no matter how complicated, can be built up by compounding a number of simple sine waves of the correct magnitudes, frequencies, and phase relationships. Fig. 6 shows the resultant complex wave

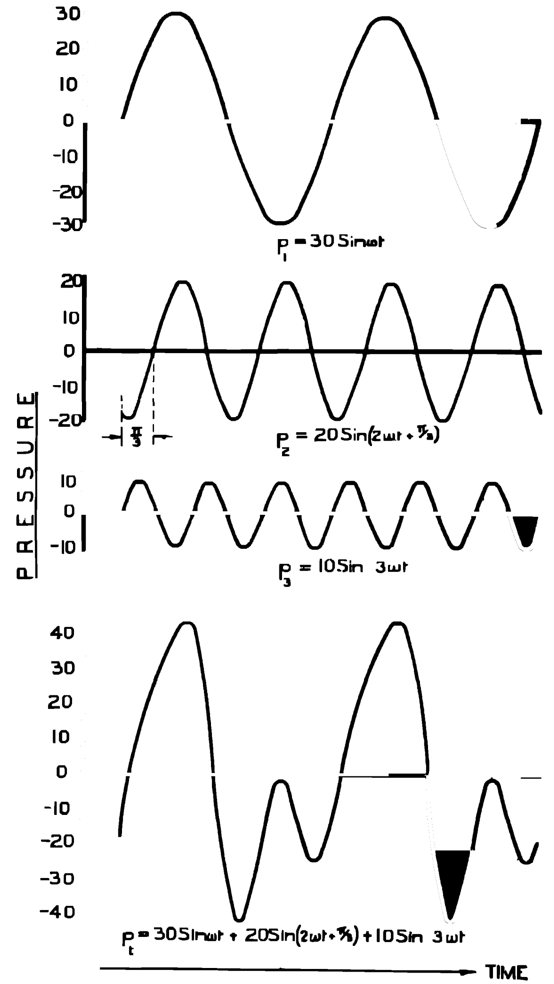


Fig. 7. The Effect of Phase Difference on Wave Shape

produced by the algebraic addition instant by instant of three sine waves of ω, 2ω, and 3ω radians per sec and amplitudes of 30, 20, and 10 units, respectively. It should be observed that the complex wave alternates at the lowest component frequency (the fundamental) and that the higher frequencies (harmonics) merely modify its shape. It is interesting to note that if the odd harmonics (engineers' notation) are added to a fundamental, the resultant wave is symmetrical about the axis,

and conversely if the even harmonics are added, the wave shape is unsymmetrical.

The effect of introducing phase difference between the component frequencies of a complex wave is illustrated in Fig. 7. The component waves are identical to those of Fig. 6, but the second harmonic is displaced from the fundamental by an angle of $\pi/3$ radians (60°). The result is a complex wave which to all appearances is totally dissimilar to the previous wave and hence it might be thought that the effect on the auditory system would also be different. This is, however, not the case since, for a continuous note such as that under consideration, the ear cannot differentiate between notes having components differing in phase. Thus, alteration of the phase relationship of a complex wave during transmission, or *phase distortion* as it is often called, has little effect on the character of the received note although the shape of the wave may be changed drastically. It should, however, be mentioned that the above is only true for a sustained note such as a vowel sound or musical note, and does not apply to explosive noises of very short duration such as consonants, drum beats, cymbals, etc. Furthermore, the ear is not responsive to changes of wave shape due to unequal attenuation of the component frequencies (*frequency distortion*). On the other hand, the ear is particularly sensitive to changes of wave shape due to *amplitude distortion*, and this factor is one of the transmission engineers' chief problems. Amplitude distortion occurs when a change of amplitude at the source is not, for some reason, accompanied by a corresponding change of amplitude at the receiving point. Amplitude distortion differs from phase distortion and frequency distortion in that the change of wave shape introduces frequencies which are not present at the source.

Aperiodic Sounds. So far consideration has been limited to sound waves which have a definite wave shape—either sinusoidal or complex—which is repeated for cycle after cycle. Such waves are designated *periodic* waves and include all vowel sounds and the notes of most musical instruments. In addition to these periodic waves there are sounds such as the consonants which have no regular repetition or cycle of sound pressures. These sounds are described by the general term *aperiodic*. Street noises and all explosive, scraping, rattling, and such-like sounds are largely aperiodic in nature. Broadly speaking, all sounds which are unpleasant or which we designate as noise are largely aperiodic, whilst musical or pleasant sounds are almost invariably waves of regular periodic repetition.

Resonance. Any object placed in the path of a sound wave is subjected to an alternating air pressure of the same frequency as the sound. If the object is free to move it will vibrate under the influence of the air pressure, the actual magnitude of the vibration depending on the strength of the air pressure and on the physical constants of the body. Now, every object has a natural tendency to vibrate at certain particular frequencies—a fact very readily shown for such objects as violin strings, tuning forks, bells, springs, etc., but also equally true for all other elastic bodies. If, therefore, a sound wave of the natural frequency of an object is made to impinge on that object, the resultant vibration will be many times greater than that produced by a wave of equal strength but of different frequency. This phenomenon is known as *sympathetic vibration* or *resonance*, and a body vibrating in resonance is often stated to be vibrating freely as compared with the forced vibrations of a body not in resonance. A very simple and convincing demonstration of resonance (and of the presence of harmonics) can be carried out on an ordinary piano. First gently depress the key of the note one octave above middle C in order to remove the damping pad from this string. Then strike middle C and release the key immediately to damp the note. It will be found that the undamped string one octave above middle C is vibrating after being energized by resonance with the second harmonic of middle C. The effects of mechanical resonance are not only of great importance in the design of telephone apparatus but are also fundamental factors in the performance of most musical instruments, the design of structures, and innumerable other fields. Everyone is aware of the annoying vibrations of pictures, ornaments, etc., which sometimes occur in the home due to the resonant effect of a certain note played on the piano. There is the story of the violinist who shattered a wineglass by playing near it a sustained note of the resonant frequency of the glass, and cases are on record where serious accidents have occurred due to the collapse of bridges, etc., when subjected to vigorous and sustained vibrations at a natural frequency.

Reverberation and Echo. When any sound wave passes from one medium to another it is subject to reflection and refraction at the junction of the two media. The energy of the original sound wave sets up two further waves, one of which continues in the second medium with a different velocity, and the other is reflected back into the first medium. The effect is somewhat similar to the familiar reflection and refraction of light rays but with two fundamental differences. Whereas a light ray changes its *direction* and its velocity when it passes

from one medium to another, a sound wave continues in the same direction, but at a different velocity, which is dependent upon the density and elasticity of the new medium. Moreover, in order to obtain reflection of light the reflecting surface must be relatively smooth, but sound reflection will occur at a surface which is by no means optically smooth. It can in fact be shown that, for efficient reflection, the undulations or unevenness of a surface must be of small dimensions as compared with the length of the wave to be reflected. Thus, light rays with wavelengths in the order of 0·0005 mm would not be reflected efficiently from the surface of a mirror marked by scratches; whereas a sound wave of say 800 c/s and having a wavelength of about 40 cm would be reflected quite well from a cliff side containing numerous small crevices. The effects of wavelength (and hence frequency) on the degree of reflection provide a major problem in the design of auditoriums where the sounds heard at any given point are the sum of the direct and reflected sound waves. Since the magnitude of the reflected waves is dependent on frequency, the net result is that certain frequencies are given undue emphasis relative to others, i.e. frequency distortion occurs.

Furthermore, since sound waves travel at quite a low velocity in air, it often happens that a reflected wave arrives at a certain point some time after the arrival of the direct air-borne wave. Under these circumstances, interference is bound to result and it may be sufficiently bad to render the original sound unrecognizable. If the reflected wave arrives within a short time of the direct wave, the auditory system cannot separate the two sounds and both are heard together as one confused noise, the effect being termed *reverberation*. When, however, the path of the reflected wave is sufficiently great to produce a long time difference, the ear can record the two as separate and distinct sounds. The reflected wave under the latter conditions is known as an *echo*.

Reflection, Standing Waves. The mechanical apparatus of Fig. 1 can be used to demonstrate the reflection of a sound wave from any point where a change occurs in the characteristics of the medium. If $W8$ is attached rigidly to the wall, there is at that point a sudden and drastic change in the mass and elasticity of the mechanical system, and the bulk of the energy is reflected in the form of a return wave along the line of springs and weights. Similarly, if $S8$ is removed and $W8$ is free, it is impossible to pass on energy and there is *total* reflection of the wave. The reflected wave will in either case also be reflected at $W1$ due to the change in the mechanical characteristics at that end of the line. These reflections will continue until the energy of the reflected wave is completely absorbed. The primary and reflection waves will not be distinguishable as separate waves, but the displacements of $W1$ to $W8$ will at each instant be the algebraic sum of all the wave pressures. Thus, at some instants the component waves will combine to produce a large displacement, whilst at other instants the pressures of the waves will neutralize each other.

If there is total reflection, the initial and reflected waves produce a condition where there is no displacement at certain points and a large displacement up to twice the initial value at other points. The appearance is that of a stationary wave along the line of springs and weights, and hence this condition is known as a *standing wave*. Exactly similar conditions exist when there is total reflection of sound, the points of constant zero sound pressure producing "blind spots" for one particular frequency.

Acoustical Impedance. Apart from the interference produced by reflection, the loss of energy is sometimes important. In the acoustical parts of a telephone system, e.g. the transmitter and receiver, it is desirable that the transfer of energy between the air-borne sound wave and the apparatus should be a maximum. Reflection can only be avoided if the response of the apparatus is such that the wave velocity is unchanged. As will be seen later, the maximum transfer of energy from one electrical circuit to another occurs when the impedances of the circuits are matched. Similarly, in order to obtain the maximum transfer of sound energy the acoustical impedances of any two media must be matched.

Acoustical impedance may be defined:

$$\text{Acoustical impedance} = \frac{\text{alternating sound pressure}}{\text{alternating rate of volume displacement}}$$

Thus, if a piston of A sq cm area oscillates in a cylinder of air with a velocity of v cm/sec, and the pressure on its surface due to contact with the column of air is p dynes, then

$$\text{Acoustical impedance} = Z = p/Av.$$

If the cylinder is very short and open to the air, the pressure built up is small and hence the impedance is low. Alternatively if the cylinder is short and closed at the end, p is great and so is the impedance.

It is the matching of acoustical impedance which largely governs the diameter and stiffness of items such as telephone receiver diaphragms, etc. A very good example of the effects of good impedance

matching can be obtained by comparing the volume of a mechanical gramophone with and without the horn. The horn is usually of the logarithmic type which is scientifically designed to introduce a very gradual change of acoustical impedance.

Acoustics of Rooms. Absorption. Until comparatively recently, the acoustical characteristics of buildings were left almost entirely to chance. Professor Sabine of Harvard University and many others have studied the causes of faulty acoustics and have formulated basic laws which enable the modern architect to determine in advance the acoustics of any proposed structure. It is now common practice to prepare sectional models of a new building and to immerse the models in a special water tank known as a *ripple tank*. Disturbances are produced on the surface of the water at any desired point and the behaviour of the resultant waves is studied. In telephony, it is important that manual switchrooms should have correct acoustical characteristics to promote efficiency and to prevent undue fatigue of the operating staff. Acoustical problems also sometimes occur at subscribers' premises where a number of telephones are to be installed in the same room.

The chief cause of bad acoustics is an excessive time of reverberation, i.e. a sound wave is reflected from the walls and other surfaces of the room so efficiently that it takes an appreciable time for the reflected waves to fall below the lower limit of audibility. To determine the reverberation time of a room, a sharp sound of standard intensity (about 60 phons) is emitted and the time for the resulting reverberation to die down to the minimum audible limit (to one-millionth of the initial intensity) is measured. In general, if the reverberation time is greater than about 1·5 sec for small rooms and 2·5 sec for large halls the interference is excessive and the acoustics are poor. To correct excessive reverberation it is necessary either to modify the sound-absorbing characteristics of the walls of the room, or to introduce additional sound-absorbing material. A standard of absorption known as the *absorption coefficient* is necessary for acoustical calculations. The absorption coefficient of any material may be defined as the ratio of the sound absorbed to the total sound impinging on the material. An open window absorbs, without reflection, all sound striking it and hence the absorption coefficient of an open window is unity. A surface which absorbs one-fifth of the sound which strikes it has a coefficient of 0 2, and 5 sq ft of such material will be required to produce the same effect as 1 sq ft of open window. The absorption coefficients of materials are to some degree dependent on frequency, but the following table gives typical values measured at a mean frequency of 500 c/s.

ABSORPTION COEFFICIENTS

Normal materials	
Brick wall, lime plaster on laths, glass	0·03
Brick wall or lath and plaster wall, painted	0·02
Woodwork, lino floor covering	0·05
Concrete, glazed tiles	0.015
Carpets	0·15
Heavy curtains	0·5
Special materials	
Acousti-Celotex (1 in. thick)	0·8
Acoustic plaster	0·3
Hair felt.	0·4
Maycoustic Asbestonite	0·8

The latter part of the table shows a number of special proprietary materials expressly designed for sound absorption. Acousti-Celotex has been used to some extent for the treatment of telephone switchrooms. It is manufactured in the form of square "tiles" of 12 in. side and in various thicknesses, which are fixed to the walls and ceiling as required. The tiles are made of a tough fibrous material known as *bagasse* which is treated to increase the resistance to moisture, fungi, termites, etc. The tiles are perforated with some 441 holes per square foot to increase the degree of sound absorption. The holes also enable the surface of the tiles to be painted without materially reducing their efficiency.

The surface area (sq ft) of any given material multiplied by its absorption coefficient gives the number of *absorption units* of that surface. Sabine showed that for a particular room

if $\quad A$ = total absorption units
and $\quad t$ = the reverberation time (sec)
then $A \times t$ = a constant for the room.

The value of the constant depends upon the cubic capacity of the room, and if V is the volume in cu ft it has been shown that:

$$V \times A \times t \text{ (sec)} = \text{a constant for all rooms} = 0{\cdot}05 \text{ approx.}$$

By means of this simple relationship it is possible to determine in advance the reverberation time of any room if the dimensions and surface materials are known. The sound absorption of the human body is very high (about 4·0 units) and the presence of a large number of persons materially reduces the reverberation time of a room. Due allowance must therefore be made for this in calculating the anticipated reverberation time.

The Human Voice. The human voice is perhaps one of the most interesting of sound generators.

The initial energy of speech or singing is derived from the air stream exhaled from the lungs which is made to pass between a pair of muscular ledges known as the *vocal cords*. The vocal cords (Fig. 8) which are situated in the larynx are normally relaxed and allow a free passage for the exhaled breath. When it is desired to speak, the vocal cords are automatically tightened and the expired breath is made to pass through a narrow aperture between them. In this condition the vocal cords are caused to vibrate at a frequency which can, to some extent, be controlled by the intensity of the muscular action. In average persons, the cords can, in effect, be roughly tuned over a range of some two octaves by alteration in the tension and in the width of the aperture. The vibrations of the vocal cords and the resultant vibrations of the air stream contain not only the fundamental frequency, but also numerous harmonics or overtones of that frequency. The air stream carrying with it the complex vibrations set up by the vocal cords, passes into the throat and is there modified by the action of the mouth and nasal cavities which form resonant chambers and which accentuate, at will, one or more of the component frequencies of the complex wave. The resonant characteristics of the nasal cavities are more or less fixed and play very little part in the production of most sounds, but the front or mouth cavity together with the throat cavity can be modified over a wide range by the action of the tongue, jaw, lips, and throat muscles. In normal speech each person produces a characteristic fundamental vocal cord note which is nearly constant in pitch, but the quality and characteristics of the speech are determined by the action of the resonant chambers. In whispering or in whistling, the vocal cords do not vibrate but the air stream is caused to vibrate at the natural frequencies of the resonant cavities.

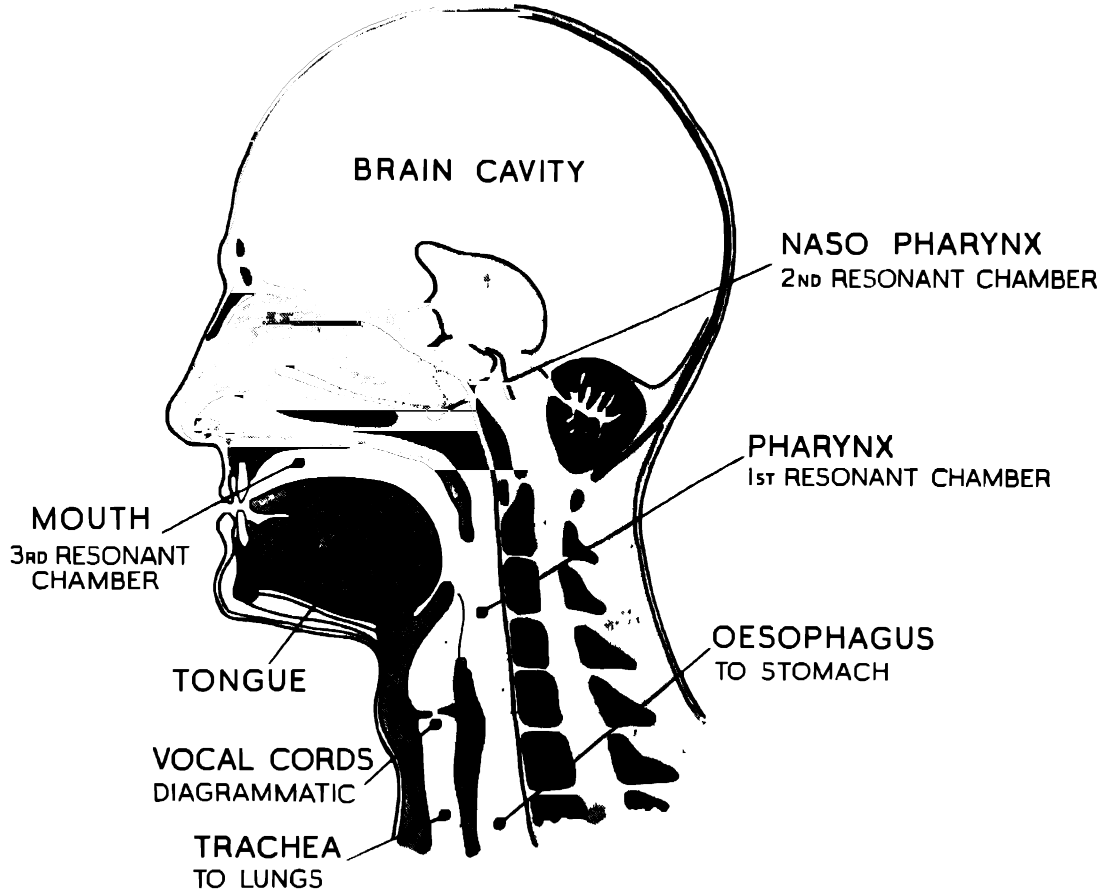


Fig. 8. The Mechanism of the Human Voice

In general, speech can be broadly divided into

vowels such as A, E, I, O, U, and consonants such as P, D, K, T, etc. Vowels are characterized by the periodic or recurrent nature of the sound waves. The vowel A, as in father, is perhaps one of the simplest types in that it is produced by holding the mouth wide open. Other vowels are formed by varying the aperture of the lips and the position of the tongue (Fig. 9) but in all cases there is no movement of the tongue, jaw, or lips which would modify the resonant characteristics of the mouth during the transmission of a vowel. Consonants can in turn be classified either as *voiced* consonants or *unvoiced* consonants, the former being produced by the combined vibrations of the vocal cords and the resonant cavities, whilst the latter are produced by the resonant cavities alone. Unlike the vowels, consonants are produced by the movement of the tongue or lips, and due to this variation or interruption of the sound wave, consonants cannot be considered as periodic or continuous waves. Some **consonants, such as P and T, are merely starting and stopping noises, whereas other consonants, such as S,** are more nearly like vowels in their behaviour.

Oscillograms of typical musical instruments and of the vowel sound "Ah" are shown in Fig. 10. Fig. 11 gives a good representation of the wave form of the word "bell," whilst Fig. 12 is a typical analysis of the vowel "Ah" showing the component frequencies of the wave and their relative strengths. Ordinary speech contains frequencies from about 60 to 10 000 c/s. The frequencies below about 300 c/s are the fundamental frequencies produced by the vocal cords, and are responsible for the greater part of the energy of speech, but experiments have shown that it is the higher frequency components which, although containing very little energy, determine to a large extent the intelligibility of speech.

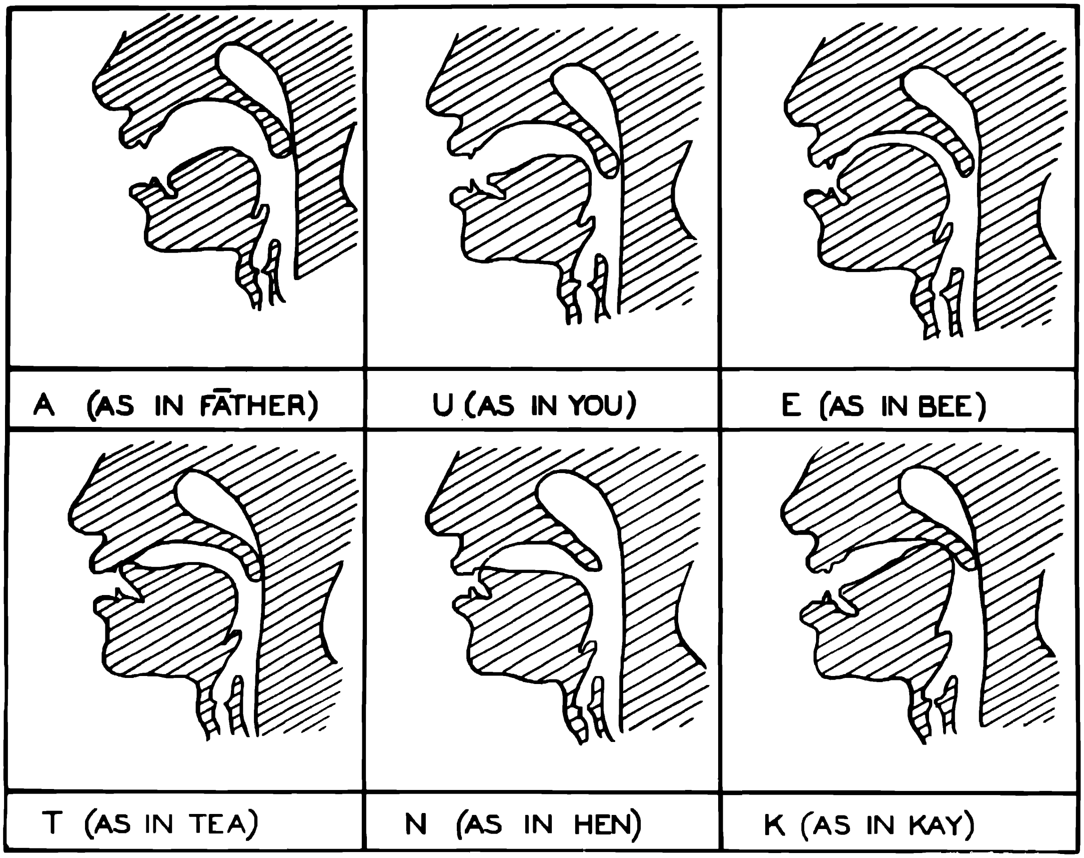


FIG. 9. POSITION OF THE TONGUE AND RELATED ORGANS FOR THE PRODUCTION OF VARIOUS VOWEL AND CONSONANT SOUNDS

Articulation. Unless cost is no object, it is impossible in any telephone system to transmit

the whole range of frequencies and, since the cost of a transmission system increases rapidly as the frequency range is widened, it becomes necessary to decide the minimum frequency range necessary to give the required degree of faithfulness. Fig. 13 (from Fletcher) shows the percentage *articulation* or *understandability* obtained when frequencies at the upper and lower ends of the spectrum are cut off. On the one hand it will be noted that the articulation falls off only slightly even when all frequencies above about 2500 c/s have been removed, but beyond this the articulation falls rapidly until at 500 c/s it is not much more than 5 per cent. Similarly, an examination of the curve showing the effect of cutting off the lower frequencies reveals that very little articulation is lost when frequencies below about 500 c/s are cut off, but if the lowest transmitted frequency is raised above this value, the articulation decreases very quickly. It may be said then that a reasonably good standard of articulation can be obtained if a frequency spectrum of from 500 to 2500 c/s is transmitted. It has recently been agreed internationally that the transmission systems of all telephone administrations should have a frequency range of from 300 to 3400 c/s and this spectrum is the standard to which plant in this country will in future be designed.

It has been stated that the lower frequency components (below about 500 c/s) contribute little to the articulation or understandability of speech.

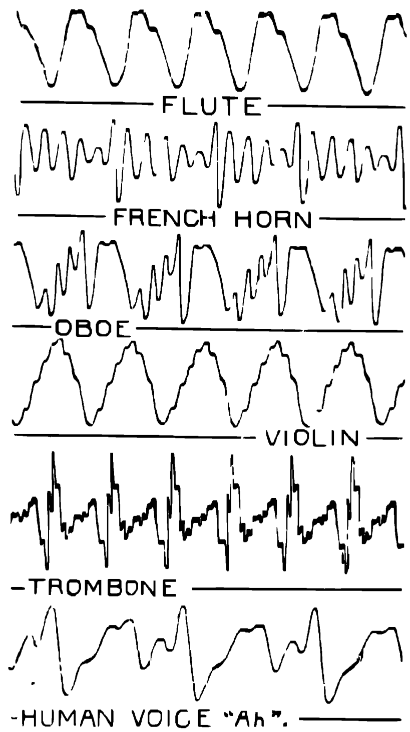


FIG. 10. WAVE-FORMS OF TYPICAL MUSICAL NOTES AND SPEECH



FIG 11. OSCILLOGRAM OF THE WORD "BELL"

These low frequencies do, however, have a substantial effect on the *naturalness* of reproduced speech. Since in a telephone system understandability is the chief aim, the naturalness of a voice is of secondary importance, but for the transmission of, say, broadcast programmes, the naturalness or quality of speech is a primary consideration.

The volume of speech received over a transmission system does, of course, also affect the intelligibility. Fig. 14 (also from Fletcher) shows the manner in which the articulation varies with the loudness. The initial loudness is the intensity ½ in. from the lips of a speaker, and from the curve it is apparent that the volume can be varied

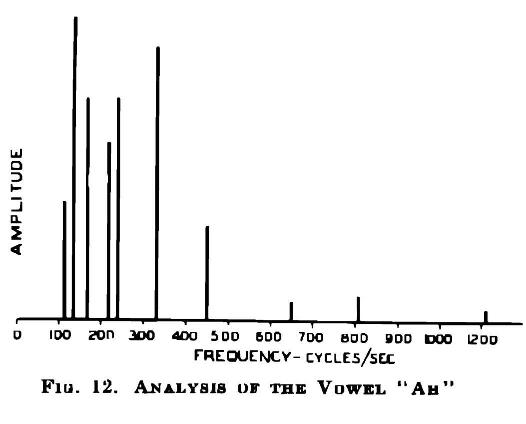


FIG. 12. ANALYSIS OF THE VOWEL "AH"

between -60 db and $+20$ db (i.e. from one-millionth to 100 times its value) without seriously decreasing the intelligibility. The best articulation is obtained when the level is about one thousandth (-30 db) of the original intensity—a value probably about the normal volume that we are accustomed to hear in ordinary conversation.

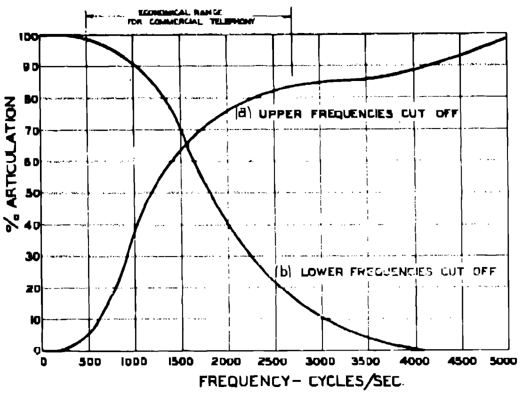


FIG. 13. EFFECT ON ARTICULATION OF CUTTING OUT (*a*) THE UPPER FREQUENCIES AND (*b*) THE LOWER FREQUENCIES

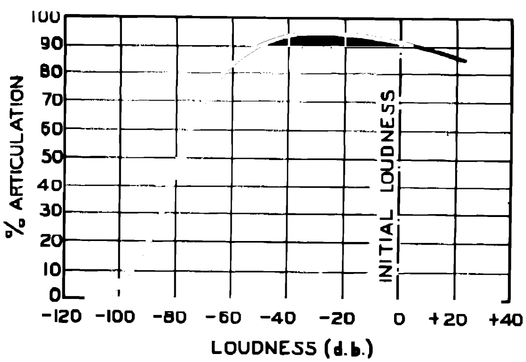


FIG. 14. EFFECT OF VOLUME UPON ARTICULATION EFFICIENCY

The initial loudness is the value half an inch from the speaker's mouth.

The Ear. Fig. 15 illustrates diagrammatically the structure of the human auditory system. The only visible part of the ear is the outer flap or *pinna* which, in most animals, can be controlled and directed to assist in the collecting of sound. The human pinna has almost lost this original function and is therefore of little benefit for hearing. Waves of sound pressure entering the *outer ear* pass along the ear canal, which is closed at its inner end by a diaphragm known generally as the *ear drum* (*tympanum*). The part of the ear immediately behind the ear drum is designated the *middle ear* and contains an assembly of three bones, the function of which is to transmit the vibrations of the ear drum to the mechanism of the inner ear. The bones of the middle ear—*the hammer, anvil, and stirrup*—form a system of levers which transform the comparatively large movements and small forces of the ear drum to smaller movements but correspondingly increased pressures at the oval window of the inner ear, i.e. they provide a mechanism for matching the acoustical impedances of the outer and inner ears.

A pressure equalizing tube (the *eustachian tube*) connects the middle ear with the outside atmosphere and ensures that the static pressures on both sides of the ear drum are balanced. The *inner ear* is a bony structure filled with liquid (lymph) and has two small openings leading into the middle ear. The two openings are called the *oval and round windows* and are closed by elastic membranes which prevent the egress of fluid from the inner ear. Vibrations of the ear drum are conveyed via the bones of the middle ear to the oval window and set up corresponding vibrations in the fluid of the inner ear.

The canal system of the ear may be considered as two main parts:

(*a*) The semicircular canals which are not directly concerned with hearing but function to maintain equilibrium. These canals have been omitted from Fig. 15 for clarity.

(*b*) The *cochlea*, which is the receiving unit for sound.

The cochlea is in the form of a spiral of some $2\frac{3}{4}$ turns and is somewhat similar in construction to a snail shell. The cochlea has a hole through the centre where the auditory nerve enters, and the inner spiral cavity is divided into two channels throughout its length by a partition made up partly by a bony shelf (the *lamina spiralis*) and partly by a flexible diaphragm (the *basilar membrane*). The upper and lower channels are connected together by a small orifice at the apex of the cochlea so that the static pressure can be equalized on both sides of the basilar membrane. The nerves enter the cochlea through the *lamina spiralis* and are terminated in some thousands of minute hair cells embedded in the basilar membrane. According to one popular theory, pressure variations at the oval window produce a pressure wave in the fluid of the upper canal. This vibration is communicated to the basilar membrane, but at any particular frequency the response is negligible except at the point where the tension and length of the membrane produce a natural resonance at that frequency. The flexible membrane does, in fact, behave like a series of tuned reeds with the

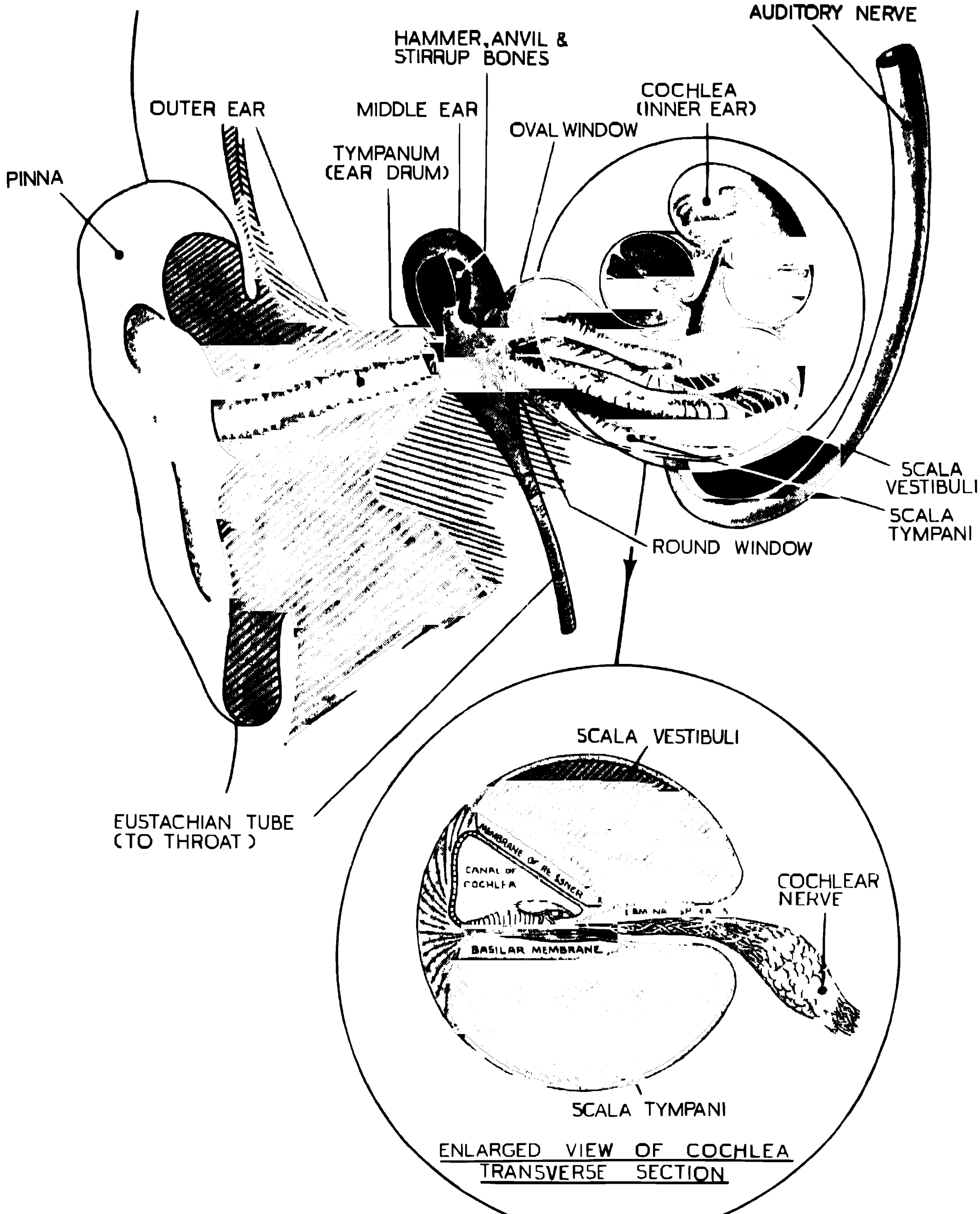


FIG. 15 DIAGRAMMATIC ILLUSTRATION OF THE ORGANS OF HEARING
The semicircular canals of the middle ear are omitted for clarity

lower notes towards the apex of the cochlea and the higher notes near the oval window. A complex wave containing frequencies of say 500, 1000, and 2000 vibrations per second produces vibration of the membrane at the three points naturally tuned to these frequencies. The nerve fibres terminated at these points transmit the stimulation to the brain, thus producing the sensation of hearing.

A sound with an intensity above the *threshold of feeling* overloads the auditory system to such an extent that the sensation is one of pain rather than of hearing. It is interesting to note that within the frequency range necessary for good articulation (say 500–2500 c/s), the ear has the maximum range of volume response. The intermediate curves of Fig. 16 show the volume of sound at different

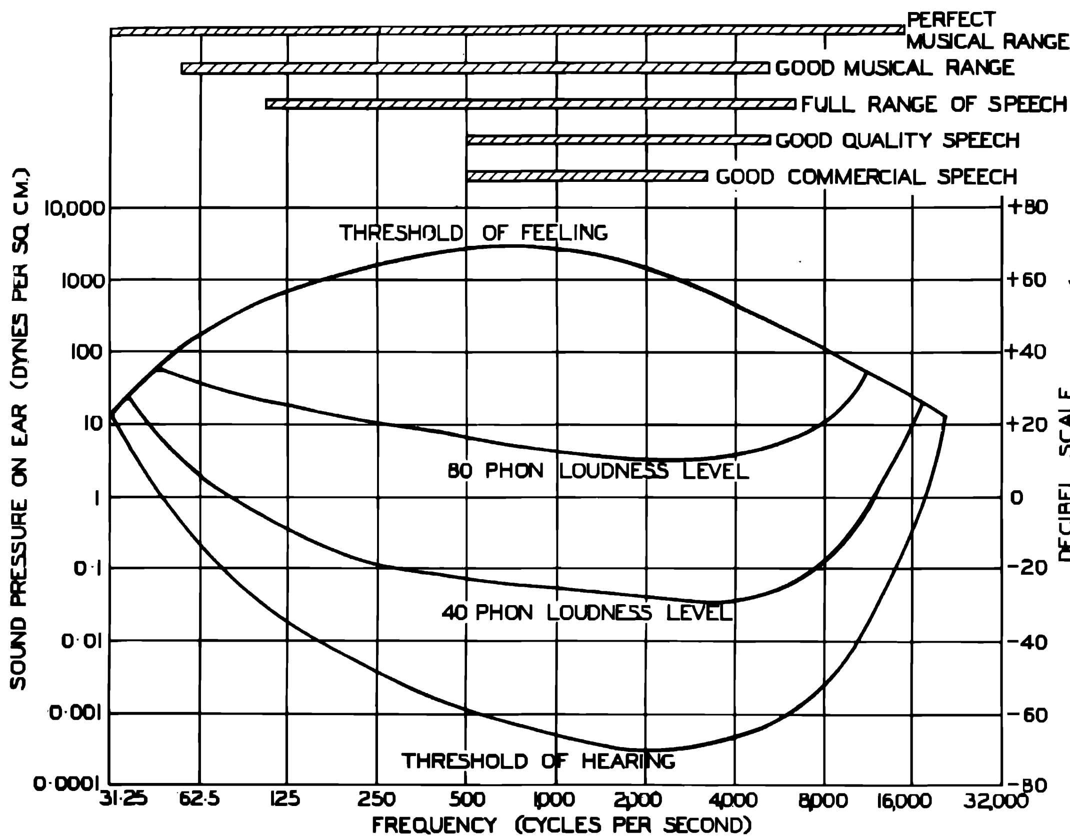


Fig. 16. Frequency and Volume Range of an Average Human Ear

The frequency range over which the average human ear will respond is in the order of 30 to 20 000 c/s, but this range varies considerably with different individuals. The sensitivity is, moreover, not uniform at all frequencies due partly to the distortion introduced by the lever system of the middle ear, and partly to the unequal damping of the basilar membrane throughout its length. The maximum sensitivity occurs at about 2000 c/s, and the sensitivity decreases as the upper and lower limits of audibility are approached. The minimum perceptible pressure (the *threshold of hearing*) at various frequencies is given in Fig. 16 which also shows the maximum intensity limits of the ear.

frequencies required to produce the same apparent volume as 40 and 80 phons of standard noise.

Electrical Transmission of Speech. The primary purpose of a telephone system is, of course, to transmit intelligible speech from one point to another as desired. It will, therefore, be advantageous at this stage to summarize the basic requirements of speech transmission:

1. The apparatus and lines of a telephone system should be capable of transmitting a frequency spectrum of from 500 c/s to 2500 c/s for commercial speech.

2. A broadening of this band to the limits of 200 and 5000 c/s will add a little to the articulation

efficiency, and will materially improve the naturalness of the transmitted speech.

3. The best articulation efficiency is obtained when the volume at the receiving end is approximately 30 db below the level of speech at the mouth of the transmitter. Any increase or decrease of volume from this level results in a reduction of articulation.

4. The transmission system should introduce a minimum of amplitude distortion. Amplitude distortion produces additional frequencies not present at the source and results in a reduction of articulation efficiency.

5. A reasonable amount of phase distortion and frequency distortion can be permitted without serious loss of efficiency.

6. The acoustical impedances should be matched at each point of conversion from sound to electrical energy and vice versa.

7. The terminal apparatus should be designed to minimize the bad effects of room reverberation.

8. Mechanical resonances within the limits of transmission should be eliminated except in so far as they can be made to assist in the above objects.

EXERCISES I

1. Explain concisely how any sound is transmitted from the source to the ear.

2. What do you understand by the following terms when applied to sound or speech: Frequency; timbre; reverberation; wavelength; damping; resonance; echo; pitch?

3. The attenuation of speech over a certain telephone circuit is 30 db. Explain this statement.

4. A certain sound has an intensity of 15 dynes/sq cm at the source and 5 dynes/sq cm at the point of reception. What is the attenuation in decibels?

5. What is a "phon"? A 1000 c/s note has an intensity of 70 phons. What is the value of the alternating sound pressure in dynes/sq cm?

6. What are "amplitude distortion" and "frequency distortion" of a complex sound wave? Which has the greater effect on the intelligibility of transmitted speech?

7. The acoustic qualities of a telephone switchroom are poor during the night period when the room is lightly staffed, but are satisfactory during the busy part of the day. How do you account for this?

8. The walls of a certain room are faced with plaster having an absorption coefficient of 0·03. The reverberation time of the room is 3 sec. What proportion of the wall surface must be covered with Acousti-Celotex (absorption coefficient 0·8) in order to reduce the reverberation time to 1·5 sec?

9. Describe, with the aid of simple sketches, how human speech is produced.

10. What is meant by "articulation"? Suggest a method of determining the articulation efficiency of a telephone circuit.

11. Explain how the sensitivity of the ear is dependent upon the intensity and frequency of the received sound. Give a typical response chart for a normal ear.

12. In what ways is speech liable to suffer impairment in the course of its transmission by telephone from talker to listener. (*C. and G. Transmission and Lines, Grade I*, 1939.)

CHAPTER II

SYMBOLS AND DIAGRAMS

Graphical Symbols. In the early days of applied electrical science the introduction of new and unfamiliar components resulted in the preparation of drawings which indicated not only the circuit connexions but also, in more or less detail, the mechanical construction of the apparatus. Whilst detailed engineering drawings and pictorial diagrams are necessary to indicate the *construction* of apparatus, they are of little value on circuit diagrams where the primary object is to describe the electrical operation of the *circuit*. Nowadays, and particularly in the complex circuits of telephony, apparatus and parts of apparatus cannot be represented in all their details on circuit diagrams. Symbols have therefore been standardized, by means of which it is possible to draw any diagram in a minimum of time while giving it the desired clearness within a convenient compass. The symbols are designed to be simple in form to facilitate drawing and to show *diagrammatically* the working of the apparatus. In a number of cases, the symbol shows the approximate outline of a common type of component, but it should be realized that the mechanical construction is of secondary importance. For instance, the same symbol is used for all kinds of relays *which are used for similar purposes*, although the type of construction may be very different.

To obtain the greatest benefits, it is essential that the symbols should, as far as possible, convey the same meaning to all concerned. In this way, owing to their being generally understood, they will be of the greatest service in the study of any publication dealing (in any language) with technical installations. With this object, a *British Standard List of Graphical Symbols for Telephony, Telegraphy, and Radio Communication* has been produced (Specification No. 530 of The British Standards Institution). This list has been agreed by the various interested parties in Britain and conforms, to a large extent, with the list of symbols issued by the International Electrotechnical Commission and the recommendations of the relevant International Consultative Committee.

A selection of the more common symbols used in the signalling and switching circuits of telephony is given in the following pages. Special attention is drawn to the following principles to be observed in using the symbols:

(*a*) Wires in contact should never be shown as a simple crossing, but should be indicated as separate tappings. Failure to observe this rule may result in confusion if the connexion "dot" is indistinct.

(*b*) Three types of arrow-head will be noted, i.e.:

Closed head for instrument pointer.

Semi-closed head for variability.

Open head for direction.

(*c*) The symbols for "slow-to-operate" and "slow-to-release" relays should be memorized. Before the symbols were standardized by international agreement the meaning of these symbols was the opposite to present practice.

(*d*) To avoid confusion with the symbol for a make contact, break contacts should, wherever possible, be placed so that the two leads are at right angles. Break contacts should never be drawn with the two connecting leads in the same straight line.

(*e*) Particular attention is directed to the difference between the following symbols:

Alternative connexions and boundary lines.

"U" points for routiner access and for jacking-in.

Change-over and make-before-break key contacts.

Locking and non-locking keys.

Bells and buzzers.

Polarized and shunt-field relays.

Bridging and non-bridging selector wipers.

Uniselector and 2-motion selector wipers.

Automatic subscriber's set and automatic exchange.

Make-before-break relay contacts and the similar mechanically operated contacts.

Relays of high impedance and those unaffected by a.c.

Non-reactive resistor and general symbol.

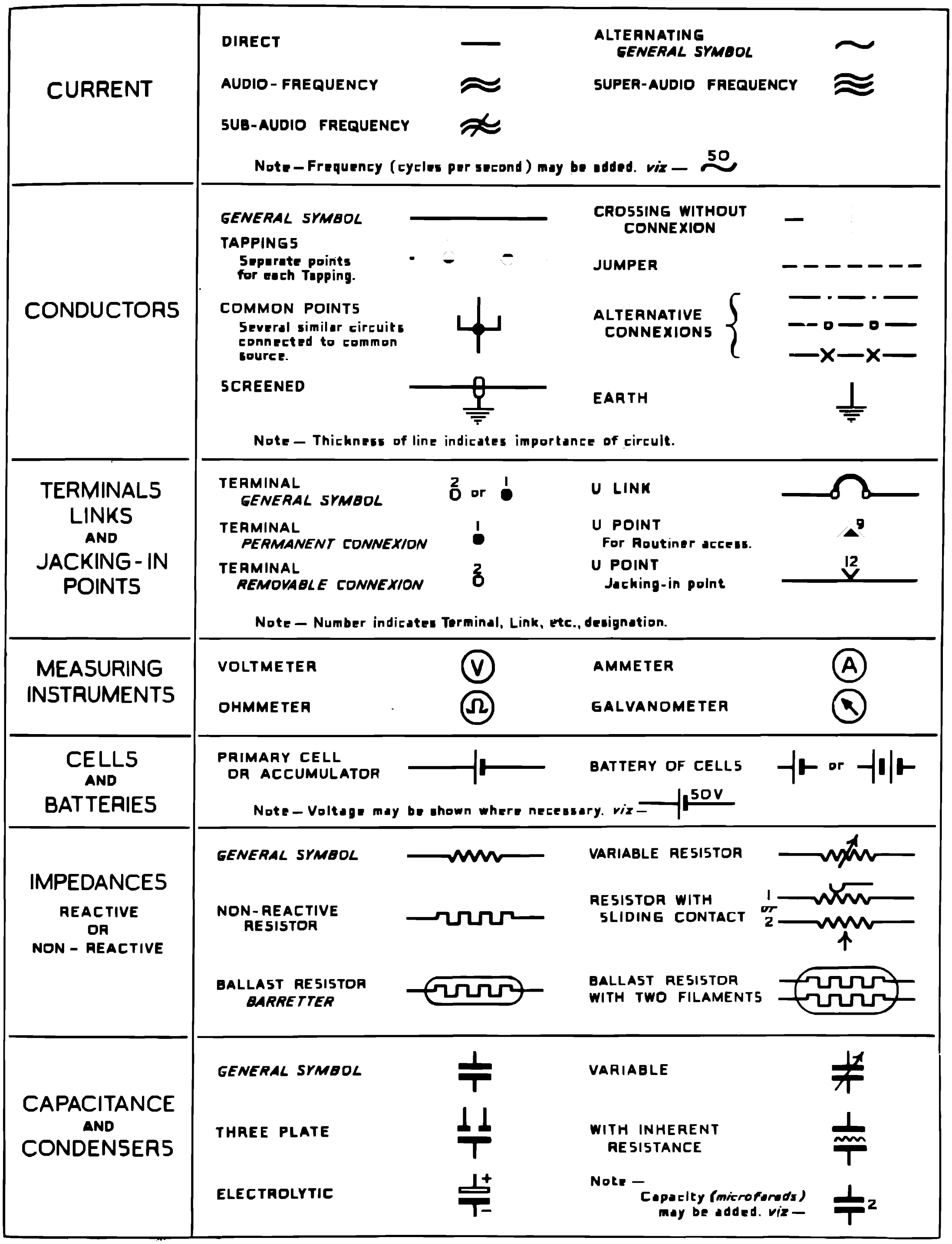


FIG. 17. GRAPHICAL SYMBOLS—I

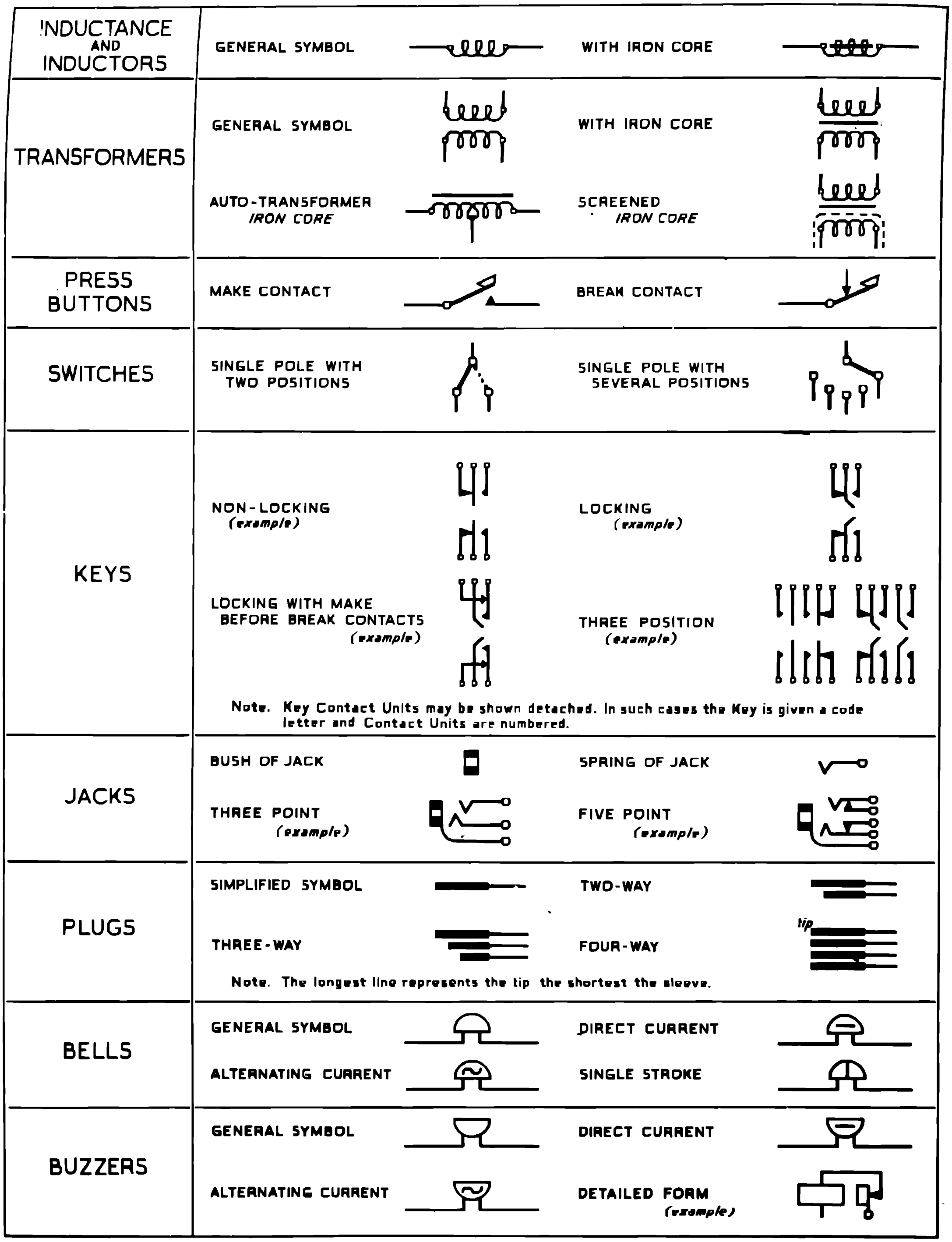


Fig. 18. Graphical Symbols—2

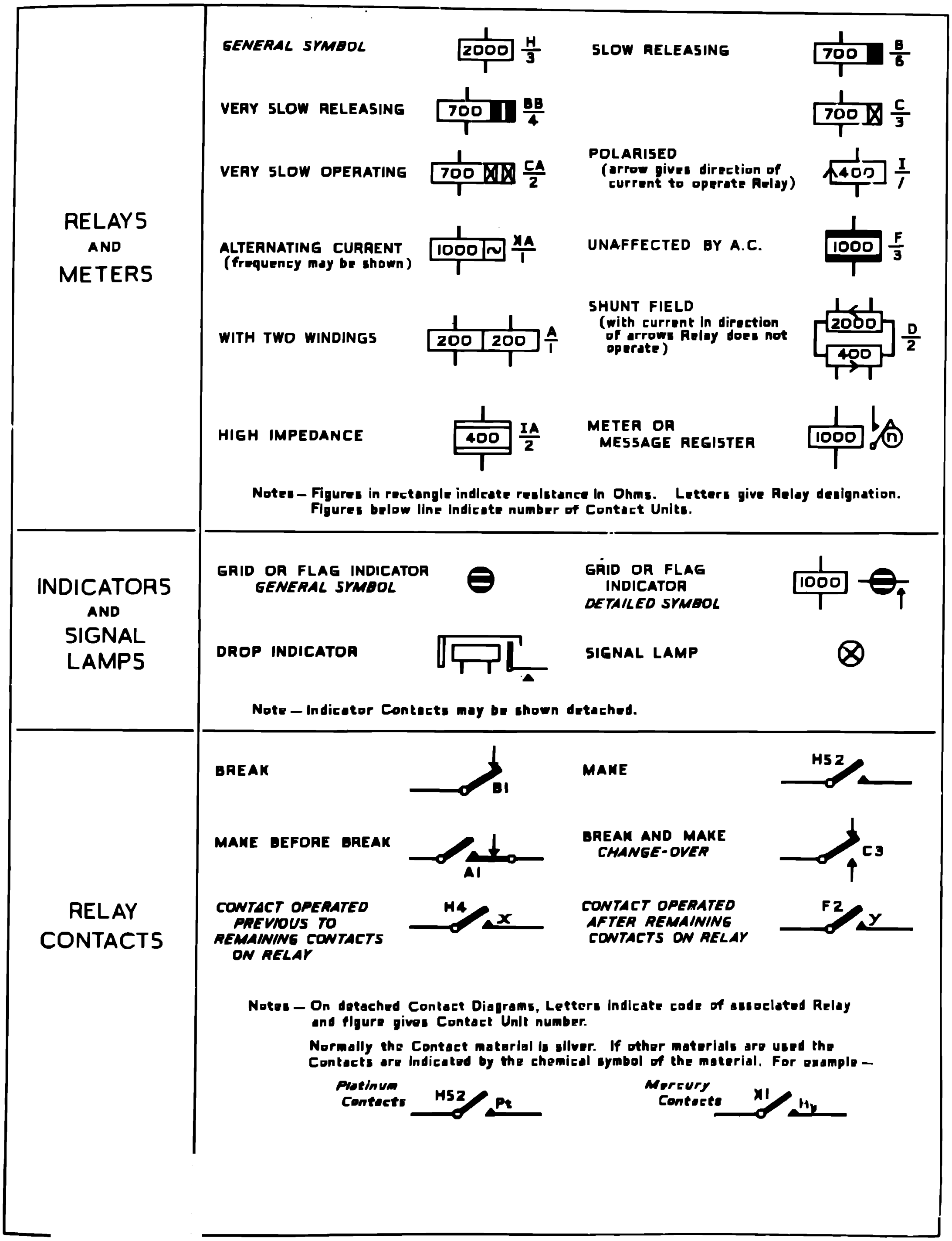


Fig. 19. Graphical Symbols—3

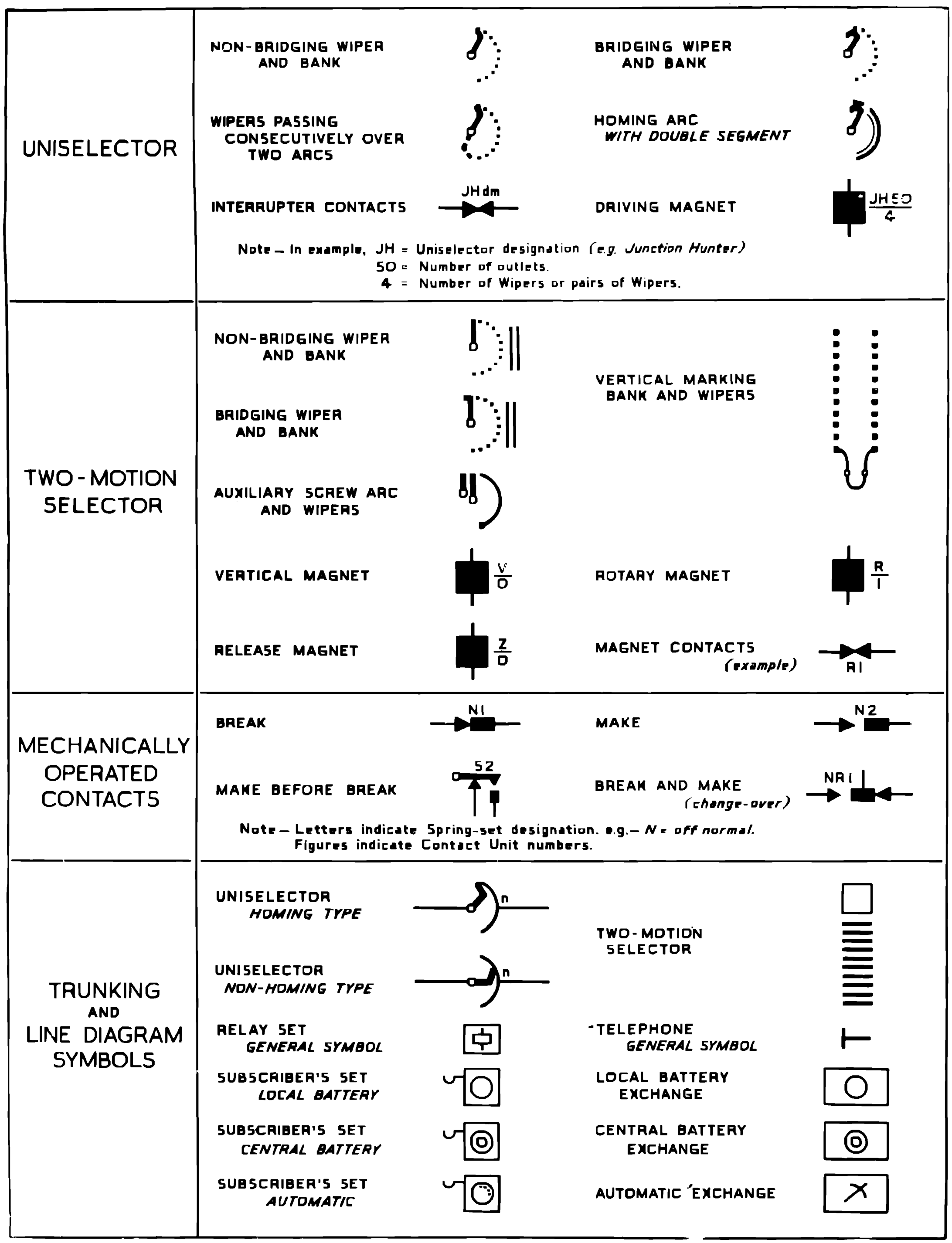


FIG. 20. GRAPHICAL SYMBOLS—4

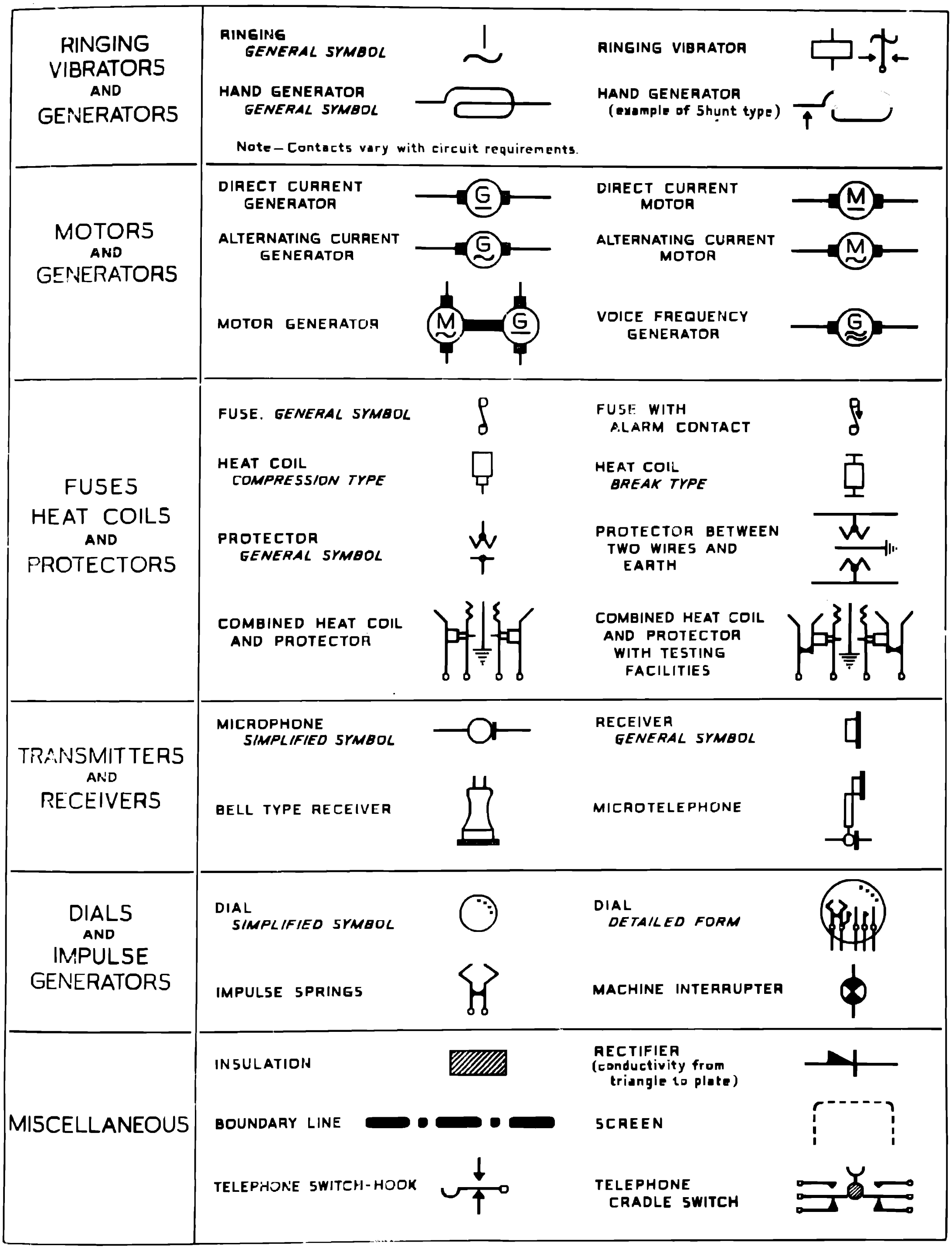


Fig. 21. Graphical Symbols—5

Common Symbols and Abbreviations

Admittance	Y
Alternating current	A.C. or a.c.
Ampere	A
Ampere-hour	Ah
Angular Frequency	ω
Anti-sidetone Induction Coil	A.S.T.I.C.
British Thermal Unit	B.Th.U.
Busy Tone	B.T.
Cable Turning Section	C.T.S.
Capacitance	C
Centimetre-gramme-second	C.G.S.
Central Battery	C.B.
Central Battery Signalling	C.B.S.
Coded Call Indicator	C.C.I.
Coin-collecting Box	C.C.B.
Combined Distribution Frame	C.D.F.
Conductance	G
Current	I
Cycles per second	c/s
Decibel	db
Decineper	dn
Dial Tone	D.T.
Direct current	D.C. or d.c.
Earth	E
Efficiency	η
Electric Force	ϵ
Electromagnetic	E.M.
Electromotive force	E.M.F. or e.m.f.
Electrostatic	E.S.
Electrostatic Flux Density	D
Farad	F
Free Line Signal	F.L.S.
Frequency	f
Group Engaged Tone	G.E.T.
Hand microtelephone	H.M.T.
Henry	H
Horse Power	H.P. or h.p.
Impedance (general symbol)	Z
Impedance with capacitative reactance (ϕ = angle of lead)	$Z\overline{/\phi}$
Impedance with inductive reactance (ϕ = angle of lag)	$Z\underline{/\phi}$
Impulses per Second	I.P.S.
Intermediate Distribution Frame	I.D.F.
Joule	J
Kil- or Kilo-	k
Kilocycles per second	kc/s
Kilovolt-ampere	kVA
Kilowatt	kW
Kilowatt-hour	kWh
Local Battery	L.B.
Magnetic Flux	Φ
Magnetic Flux Density	B
Magnetizing Force (Magnetic Field Strength)	H
Magnetomotive Force	F
Main Distribution Frame	M.D.F.
Meg- or Mega-	M
Micro-	μ
Milli-	m
Miscellaneous Apparatus Rack	M.A.R.
Mutual Inductance	M
Number	N
Number Unobtainable Tone	N.U.T.
Ohm	Ω
Period	T
Permeability	μ
Phase Difference	ϕ
Pneumatic Distributing Position	P.D.P.
Pneumatic Filing Position	P.F.P.
Potential Difference	V
Power	P
Private Automatic Branch Exchange	P.A.B.X.
Private Branch Exchange	P.B.X.
Private Manual Branch Exchange	P.M.B.X.
Quantity of Electricity	Q
Reactance	X
Reluctance	S
Resistance	R
Resistivity	ρ
Ringing Tone	R.T.
Root Mean Square	R.M.S. or r.m.s.
Self-inductance	L
Simple Harmonic Motion	S.H.M.
Sleeve Control	S.C.
Straightforward Junction	S.F.J.
Susceptance	B
Susceptibility	κ
Traffic Unit	T.U.
Trunk Distribution Frame	T.D.F.
Unit Automatic Exchange	U.A.X.
Visual Engaged Signal	V.E.S.
Voice Frequency	V.F.
Voice Operated Relay	V.O.R.
Volt	V
Volt-ampere	VA
Watt	W
Watt-hour	Wh
Wavelength	λ

Schematic Diagrams. A diagram which is prepared primarily to illustrate the operation of a circuit is known as a *schematic diagram.* In the signalling and switching circuits of telephony, the relay is by far the most common component. For a large number of years it was considered desirable to draw the contacts of each relay alongside the symbol for the relay coil. This practice was continued for some time after the introduction of automatic switching and, as the circuits grew in complexity, it became more and more difficult to understand readily the working of the circuits. A system was therefore evolved of coding the relays and contacts so that the coils and contacts could be dissociated and placed at convenient points

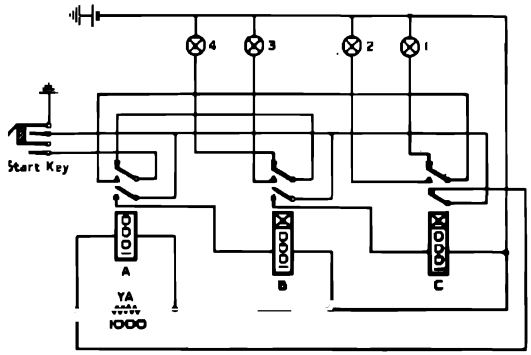


FIG. 22. SIMPLE 3-RELAY CIRCUIT DRAWN ON THE "ATTACHED CONTACT" PRINCIPLE

on the diagram. Such diagrams are known as *detached contact diagrams* to distinguish from the earlier *attached contact* system. It has been found that, after a little practice, there is no difficulty in associating mentally each contact with its appropriate coil even though they are placed at widely different points on the diagram. The simplification of diagrams attainable by the use of the detached contact system is so marked that the older attached contact method has now been entirely superseded—even for the simplest of circuits.

Detached Contact Diagrams. Under the detached contact system a relay is designated by a combination of a letter and a figure, e.g. $\frac{B}{3}$. The letter identifies the relay and the figure shows the total number of contact units. Where a relay coil is used as a retard without contacts, it is designated by a code letter and the figure 0 below the line, e.g. $\frac{I}{0}$. As stated above, relay contacts may be placed at any convenient point on the diagram (i.e. detached from the relay coil) and are indicated by the relay code letter followed by the contact unit number (e.g. *B*1, *B*2, or *B*3). A relay having more than one winding should not be shown with the windings separated. If desired, keys may also be shown with their contact units "detached." In such cases, each contact unit is designated by the key letter code (usually commencing with the letter *K*) followed by the contact unit number.

Two-motion selector magnets are lettered in the same way as relays, and the associated wipers and

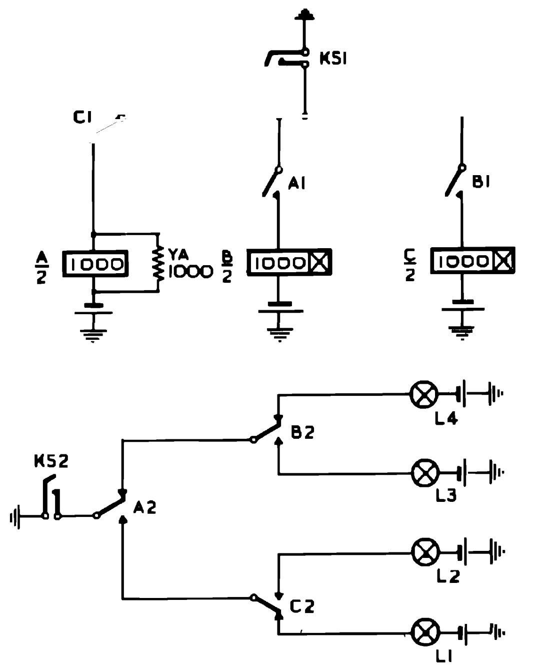


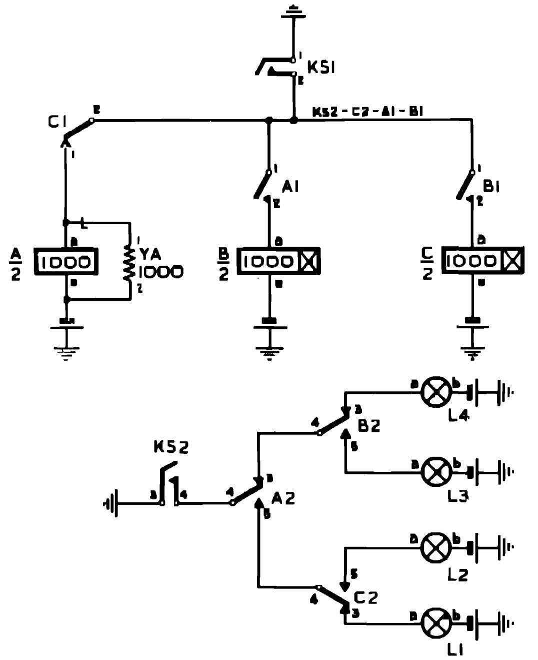
FIG. 23. CIRCUIT OF FIG. 22 DRAWN AS A DETACHED CONTACT DIAGRAM

banks are given the circuit description (—, +, *P*) or are numbered serially. The coding of uniselectors is somewhat different. The magnet is coded by means of two letters followed by a number, with a further number in the denominator (e.g. $\left.\frac{JH50}{4}\right)$. The letters describe the uniselector (e.g. Junction Hunter), the following figures (e.g. 50) give the number of outlets, whilst the denominator (e.g. 4) indicates the number of wipers (or pairs of wipers). Any interrupter contacts associated with the magnet are described by the uniselector code followed by the letters *dm* (e.g. *JHdm*).

Diagrams should show the apparatus in the *unoperated position* unless specifically stated otherwise. It is also the general practice to draw diagrams so that, in studying the operation, they are

read from left to right or from top to bottom. As a further aid, it is now the practice on new circuits to connect the moving spring of simple make and break contacts to the earth side of the circuit.

Fig. 23 shows a simple detached contact diagram of a three-relay circuit to flash four lamps in rotation when the start key is operated. It is interesting to compare the illustration with Fig. 22, which shows the same circuit drawn on the "attached contact" system.



Earth. E-KS1-KS3.
Batt. B-YA2-C₂-A₂-B₂-L4b-L3b-L2b-L1b.

Fig. 24. "Routed-schematic" Diagram of the same Circuit

Routed Schematic Diagrams. The detached contact schematic diagram is very satisfactory as a means of illustrating the general circuit arrangements and the method of operation of a piece of equipment. It does not, however, give sufficient information for the tracing and rectification of wiring faults and it is of very little value for use in the factory wiring of apparatus.

Until a few years ago a separate wiring diagram was provided for each piece of apparatus in addition to the theoretical or schematic diagram. These wiring diagrams, in general, followed the normal electrical engineering practice of reproducing a rear view of the equipment and showing the actual routes of the wires between the components. Such diagrams were reasonably satisfactory for the comparatively simple manual circuits, but became impossibly complicated with the growing complexity of automatic telephony.

Pictorial wiring diagrams are not now prepared and have been replaced by *routed schematic* diagrams which retain the simplicity of the original theoretical diagram, but also include all the necessary wiring information. Fig. 24 shows a "routed" version of the simple three-relay circuit already considered, and should be compared with the pictorial wiring diagram (Fig. 25) which is required

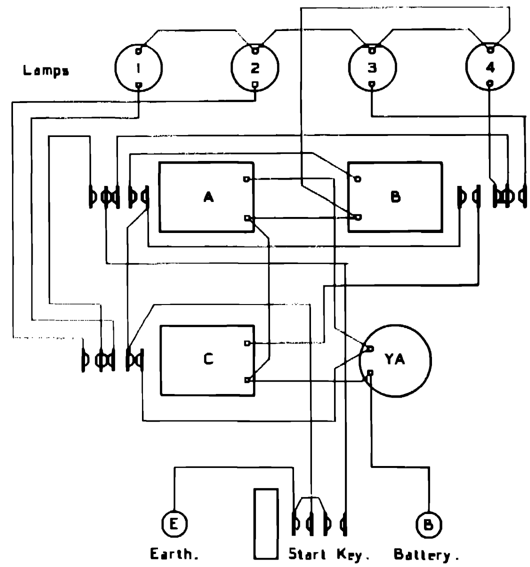


Fig. 25. Pictorial Wiring Diagram of the Circuit of Fig. 24

to give the same information. The following conventions and principles are adopted on the routed schematic diagram:

(*a*) All apparatus connexion tags are numbered or lettered and all spare tags, relay contacts, etc., are shown.

(*b*) When a wire merely links together two connexion tags, the simple line of the ordinary schematic diagram fully describes the run of the wire and no additional information is necessary.

(*c*) When a wire connects together three points it must be "looped" in and out of one of the points. The looping point is indicated on the diagram by the letter "L" drawn across the "wire line" as near as possible to the connexion tag concerned.

(*d*) When a wire connects together four or more points, the route is described by placing at a convenient point on the wire a group of code letters, etc., to show the actual run of the wire.

The physical connexions are taken from tag to tag in the order shown.

(e) When a "common" such as earth or battery is not shown as a connecting line on the schematic diagram, the routing is indicated by a separate group of tag designations placed at any convenient point on the diagram.

The Studying of Diagrams. The explanation of each individual stage in the operation of a circuit is usually self-evident, and very few students of telephony have any real difficulty in following circuit operations if a chronological description and a diagram are available. The author has found, however, that quite a number of students can readily follow a circuit description, but cannot afterwards reconstruct the circuit operation without the aid of the descriptive matter. The reading of circuit diagrams is pointless unless one can learn from such reading the principles and reasons for the design together with the practical application of these principles. Telephone switching and signalling circuits are almost innumerable and new circuits are being added daily. It is impossible to memorize even a fraction of the total number of circuits and the reader should therefore concentrate on developing his ability to understand diagrams from a knowledge of the basic principles of circuit design. The following suggestions may assist:

(a) Always be certain of the facilities provided by the circuit before attempting an examination of the detailed circuit operation.

(b) Study and memorize the elements which are common to a large number of circuits, e.g. the stepping circuit of an automatic selector. Time spent in this direction will be amply repaid later.

(c) After reading a circuit description, try to memorize the elements which are peculiar to that circuit rather than the circuit as a whole. It is a useful practice to extract any such elements from the remaining circuit details and to prepare small elemental diagrams.

(d) Possibly the greatest difficulty in understanding a lengthy circuit description is to remember relay operations which have taken place earlier. It is extremely helpful to develop a system of "shorthand" notes to summarize the relay operations which have already occurred. One scheme is to draw a horizontal line on a convenient piece of paper and, starting on the left, to place above the line the codes of relays in the order of their operation. Similarly, when a relay is released its code letter is placed below the line. The scheme may be amplified by placing notes above the relay operations to indicate the change in external conditions which has produced the operation (e.g. "operator answers," "subscriber clears," etc.). The space below the line can be used to show the signals, etc., sent out from the circuit at the various stages (e.g. "calling lamp lights," "dial tone to caller," etc.). When completed, this chart shows in a compact way the sequence of relay operations. In most circuits there are several separate courses due to alternative conditions (e.g. subscriber engaged, subscriber free, etc.). In these circumstances, one horizontal line must be drawn for the operations which are common to calls of all types, together with separate lines for each alternative.

(e) Where the sequence of operations is determined by the relative operate and release lags of the relays, it is sometimes difficult to determine the true sequence from an examination of the circuit. In these circumstances, it is most helpful to draw a diagram on a time base to show the exact time when each relay is energized, when the contacts operate, when the relay circuit is broken and when the contacts finally restore. This diagram is, in effect, a simplified oscillogram of the current in the relay coils and the operation of the contacts.

(f) In modern circuit design, a relay sometimes has several different functions. For instance, the operation of relay *X* alone may produce certain effects, whilst when relay *X* is operated along with relay *Y* an entirely different result is obtained. It is good practice, after reading through a circuit description, to summarize the way in which relay combinations are used to produce various conditions.

(g) The contacts of any one relay often function at different stages in the circuit operation. At any specific stage in the operation, it is both distracting and confusing to consider contacts which do not actually break or make a circuit at that stage. The remaining contacts will generally be explained later when they carry out some definite function. To ensure that every contact has been considered, it is sometimes helpful to write down each contact number as its function is explained. If, at the end of the description certain contacts are unaccounted for, the circuit should be re-examined to ascertain the purpose of the contacts. Very often contacts are inserted to meet unusual misoperation or fault conditions. In other cases the contact itself may have no direct function but is provided to neutralize the effects of other contacts at various stages in the operation.

(h) Throughout this volume, any reference to a contact which is operated is shown in heavy type (e.g. ***B*3**) whereas unoperated contacts are indicated in normal type (e.g. *B*3). Where the purpose of a contact is obvious from an examination of the diagram or has been explained previously in connexion with some other circuit element, it is

sometimes omitted from the text to avoid an unduly long description for each circuit.

Example. The following examination of the simple three-relay circuit of Fig. 23 may serve to summarize the above principles and suggestions.

First of all, what are the facilities provided by the circuit? When the start key is operated, the relays interact in such a way as to flash the lamps consecutively in the order *L*1, *L*2, *L*3, *L*4, *L*1, *L*2, etc. No two lamps are operated at the same time and the rotational operation continues until the start key is restored.

When the start key is thrown, earth from ***KS*1** energizes relay *A* (which is fast to operate) via *C*1. Contact ***A*2** lights *L*1 via *C*2 from the earth at ***KS*2**. At the same time, ***A*1** completes a circuit for relay *B* which operates after a lag. ***B*1**, in turn, energizes *C* which also operates after a lag period. ***C*2** disconnects the circuit for *L*1 and lights *L*2. ***C*1** breaks the *A* relay circuit but the non-inductive shunt maintains the *A* relay for a period. In due course *A* releases and at *A*2 breaks the circuit of *L*2 and completes the circuit for *L*3 via ***B*2**. *A*1 releases *B* and, after a release lag, *B*2 changes over the lamp circuit from *L*3 to *L*4. *B*1 disconnects *C* and, after a further release lag period, *C* releases to reclose the *A* relay circuit at *C*1. *A* operates to disconnect *L*4 and to relight *L*1. *A*1 operates *B* and the cycle is repeated for so long as the start key is thrown.

The operation of this circuit can be summarized, as suggested in paragraph (*d*) on page 29, as follows—

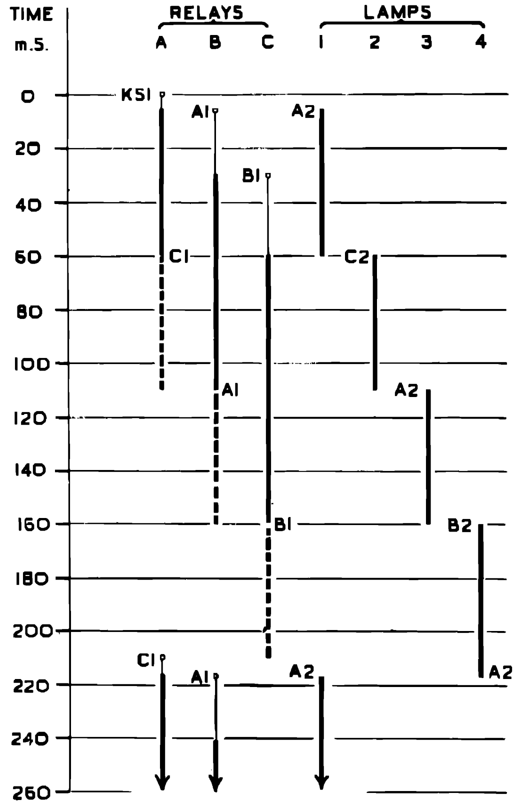
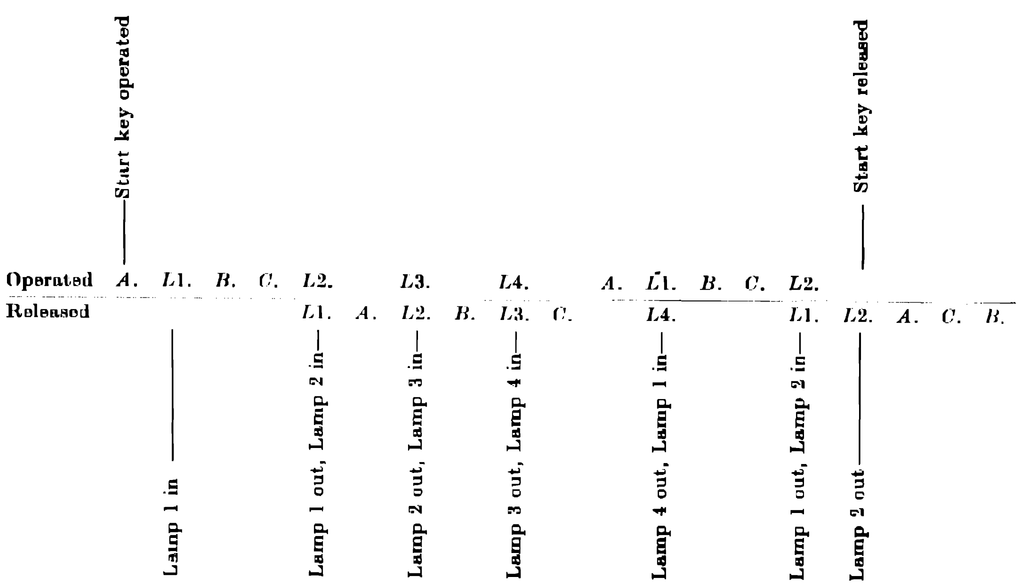


Fig. 26. "Time-base" Chart to Study the Sequence of Relay Operations



The order in which the relays and lamps are operated is shown above the horizontal line, whilst the order of release is shown below the line. It is very easy to determine which relays are operated at any particular instant by looking back along the line to the left. The only external conditions which control the circuit operation are the throwing and restoration of the start key. These are shown above the line. Similarly, the lighting of the lamps is the only result of the circuit operation and is shown below the line.

If a closer examination of the circuit is required, a chart similar to Fig. 26 can be prepared. The time (in milliseconds) from the receipt of start conditions is shown on the left, whilst a small circle shows the instant when each relay is energized. The contact which closes the relay circuit is shown to the left of the circle. The instant when each relay operates its contact units is shown by the commencement of the heavy full line. When the relay circuit is disconnected, the full line changes to a broken line and the contact which breaks the circuit is shown on the right. The broken line shows the release lag of the relay and terminates when the contacts restore to normal. This diagram in conjunction with the schematic circuit diagram gives a very clear picture of the circuit changes which take place. It is apparent that lamps 2 and 3 are lighted during the release lags of relays *A* and *B* respectively. Lamp 1 is alight from the time of operation of *A* until *C* operates, whilst lamp 4 is alight for the release lag of *C* plus the operate lag of *A*.

Finally, the relays are used in the following combinations to control the lamps:

A operated, *C* released—Lamp 1
A operated, *C* operated—Lamp 2
A released, *B* operated—Lamp 3
A released, *B* released—Lamp 4

EXERCISES II

1. Draw, in symbolic form, the following pieces of apparatus:

(*a*) A slow to release relay of 1000 Ω resistance.

(*b*) A change-over contact which is the fourth unit of a relay coded *H*.

(*c*) A three-position key with two locking change-over contact units and two non-locking make-before-break contact units.

2. Explain what is meant by a "detached contact" circuit diagram. What conventions and rules are adopted in the preparation of such a diagram?

3. What is the purpose of a "routed schematic" diagram? Explain the method of preparing such a diagram.

4. Describe a method of analysing a circuit operation by means of a graphical chart.

5. A model road traffic signal consisting of the usual red, amber, and green lights is to be controlled from a distance by means of three relays *X*, *Y*, and *Z*. The contacts of the relays must give the following sequence of lights:

No relays operated	—	No lights
Relay *X* operated	—	Red light
Relays *X* and *Y* operated	—	Red and amber lights together
Relays *X* and *Z* operated	—	Green light
Relays *Y* and *Z* operated	—	Amber light

Give a schematic diagram of the lamps and control contacts. It may be assumed that an earth connected battery is available.

6. Extend the diagram of Question 5 to show how the relays *X*, *Y*, and *Z* can be controlled from a distance over a 3-wire circuit by means of four non-locking lever keys marked Red, Red/Amber, Green, and Amber. An earth is available at the control point.

7. Draw a schematic diagram of the following components of a simple series circuit:

A 50-volt battery shunted by an electrolytic condenser.

A locking type lever key with a simple make contact.

A fixed resistor of 1000 Ω.

An ammeter with a non-inductive shunt.

A variable resistor.

An iron cored inductor.

A slow-to-release relay of 500 Ω with a metal rectifier in parallel.

CHAPTER III

TRANSMITTERS AND RECEIVERS

The history of the electric telephone dates from 1854 when Charles Bourseul, a Frenchman, published an article (*L'Illustration*, 26th August, 1854) in which the following remarkable passages occur:

"Suppose that a man speaks near a movable disc sufficiently flexible to lose none of the vibrations of the voice and that this disc alternately makes and breaks current from a battery. You may then have, at a distance, another disc which will simultaneously execute the same vibrations. It is true that the intensity of the sounds produced will be variable at the sending point at which the disc vibrates by means of the voice, and constant at the receiving point where it vibrates by means of electricity, but it has been shown that this does not change the sounds. . . . The present state of acoustic science does not permit us to declare that this will be precisely the case with syllables uttered by the human voice. The mode in which these syllables are produced has not yet been sufficiently investigated. It is true that we know some are uttered by the teeth, others by the lips, etc., but that is all. However this may be, observe that the syllables can only reproduce upon the sense of hearing the vibrations of the intervening medium. . . . It is certain that in a more or less distant future speech will be transmitted by electricity. I have made experiments in this direction: they are delicate, and demand time and patience, but the approximations obtained promise favourable results."

This undoubtedly contained the germ of electric telephony, but it was Phillip Reis, a German physicist, who, in 1861, actually carried the idea into effect. The Reis transmitting instrument (or *transmitter*) consisted of a membrane with a contact at its centre by which the circuit was made and broken due to the vibration of the membrane under the action of sound. The receiving instrument (or *receiver*) consisted of an iron rod inside a solenoid, and relied for its operation on the phenomenon discovered some years before that an iron bar when magnetized emits a faint click. The effect is in fact due to the molecular rearrangement of the iron as a result of magnetization.

Although it was claimed that the Reis telephone would reproduce the sound impinging on the transmitter diaphragm, it is apparent that the reproduction must have been in respect of pitch only. By the very action of the transmitter in making and breaking the circuit it is impossible to reproduce either the intensity of the sound or any of the complexities of a normal speech wave. It is possible that by careful adjustment of the transmitter a *variable contact* rather than a definite make-and-break action could be obtained with the Reis telephone and, although unknown at the time, the variable resistance may have accounted for the claims of the instrument to reproduce recognizable speech.

Bell's Electromagnetic Telephone. Credit for the production of the first practical telephone is due to Alexander Graham Bell. In 1875, Bell was experimenting with a harmonic telegraph which consisted at the transmitting end of a series of buzzers with reeds mechanically resonant at different frequencies. At the receiving end a number of electromagnets were provided with reeds tuned to the same frequencies as the transmitting buzzers. According to the now famous story, the interrupter contacts of one of the buzzers had welded together and, in an effort to free the contacts, Bell's assistant —Thomas A. Watson—plucked the reed of the transmitter. Fortunately at this instant Bell was attempting to tune the corresponding receiver and recognized the reproduced sound of the plucking of the faulty transmitter reed.

In the following year (1876) Bell filed his first patent for an electric telephone. In principle the arrangements then proposed were essentially similar to the harmonic telegraph with improvements to adapt the instruments for speech transmission. These principles are used, at least so far as the receiver is concerned, in the telephone of to-day and are illustrated in Fig. 27. Each instrument was similar in construction and consisted of an iron-cored electromagnet fitted with an L-shaped yoke to the free extremity of which an iron armature was loosely pivoted. The armature was mechanically connected to the centre of a flexible membrane stretched across the bottom of a funnel-shaped mouthpiece. The two instruments were connected together with a pair of wires, and a battery was included in series with the circuit.

In the static condition, the direct current flowing round the electromagnet windings produces a magnetic flux, the value of which depends on the strength of the current and on the reluctance of the magnetic circuit. The major portion of this reluctance is due to the air gap between the end of the electromagnet and the movable armature. Hence any vibration of the armature, produced by speech impinging on the flexible diaphragm, varies

the length of the air gap in the magnetic circuit. Variations in the length of the air gap in turn produce corresponding variations in the total flux. The flux, in cutting the turns of the electromagnet winding, induces an e.m.f., the magnitude of which depends upon the rate at which magnetic lines of force cut the turns. By this means an alternating e.m.f. is generated which results in a flow of alternating current round the circuit.

In the idle condition, the direct current flowing in the receiving telephone magnetizes the core of the electromagnet and so produces a static pull on the armature and hence on the flexible diaphragm. The addition of an alternating speech current to the steady direct current results in alternate increases and decreases of the magnetic pull on the armature, which in turn causes the receiver diaphragm to vibrate in a manner similar to that of the transmitting instrument.

Bell's Liquid Transmitter. It was not long before Bell realized that the limitation of his telephone was the comparative insensitivity of the electromagnetic transmitter. The initial energy of speech is small, and after allowing for the absorption of a substantial portion of this energy in overcoming the mechanical forces of the diaphragm, etc., the electrical energy transmitted to line is insufficient to give adequate volume except on short lines. Bell's liquid transmitter, patented almost immediately after the filing of the first patent, was based on an entirely different principle. The diaphragm had attached to its centre a fine needle, the lower extremity of which just dipped into a cup of acidulated water (Fig. 28). Vibration of the diaphragm caused variations in the area of contact between the needle and the liquid, and hence produced corresponding variations in the resistance of the transmitter. By this means the direct current from the battery was varied or *modulated* and the fluctuating current in passing through the distant receiver gave the required vibratory tractive force on the armature and diaphragm. The variable resistance transmitter is of course basically different to the earlier make-and-break transmitter in that the former will respond to variations in intensity and wave form whereas the latter does not. It is, moreover, considerably more sensitive than the electromagnetic transmitter since the comparatively weak energy of speech is used merely to control the much greater energy given out by the battery. All the initial speech energy is in fact completely absorbed by the movement of the diaphragm against the frictional forces of the liquid and the mechanical forces within the diaphragm itself.

The Development of the Variable-Resistance Transmitter. Variations and improvements on the basic variable resistance transmitter of Bell followed each other in rapid succession. In 1877, Emile Berliner produced a transmitter consisting of a metal diaphragm against which was pressed a metal ball. Vibration of the diaphragm produced corresponding variations in the contact pressure between the diaphragm and ball and so gave the

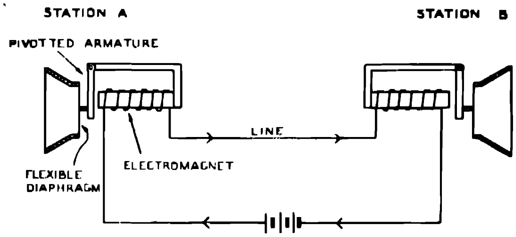


FIG. 27. PRINCIPLE OF BELL'S ORIGINAL ELECTROMAGNETIC TELEPHONE

required variable resistance. A year later, Professor Hughes read his historic paper before the Royal Society in which he described his discovery that any system of loose contacts will form a telephone transmitter. At about the same time Edison was investigating various combinations of materials to obtain the best elements for a variable-resistance

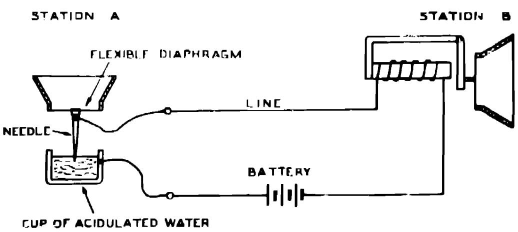


FIG. 28. PRINCIPLE OF BELL'S LIQUID TRANSMITTER

transmitter. He found that carbon gave the most satisfactory results and produced a commercial transmitter utilizing this material. In the Edison transmitter the flexible diaphragm rests on an ivory button attached to a platinum plate which is in contact with a disc of lamp black (carbon). When the diaphragm is made to vibrate by the action of sound waves impinging upon it, the vibrations are communicated to the platinum plate which, by varying the pressure on the carbon disc, varies the resistance of the instrument. It is now recognized that the action largely depends, not upon the reduction in the resistance of the carbon due to its compression, but upon the variation in the area of contact between the carbon and the platinum plates.

Various other inventors produced transmitter designs employing a block or pencil of carbon in conjunction with a metal point or surface, but the next real step forward was the use of granular carbon suggested by the Reverend H. Hunnings. The Hunnings transmitter (Fig. 29) consisted of a platinum diaphragm and an electrode, the space between them being filled by carbon granules. The principle of its action relies upon the motion of the diaphragm producing greater or less intimacy of contact between the granules and thus varying the electrical resistance between the front and back electrodes.

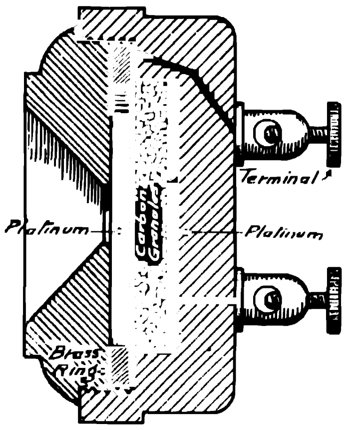


FIG. 29. EARLY FORM OF CARBON-GRANULE TRANSMITTER
The Hunnings transmitter.

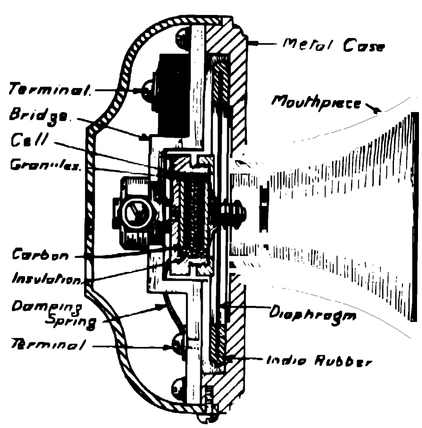


FIG. 30. SOLID BACK TRANSMITTER
P.O. transmitter No. 1.

This instrument gave much better results than any of the transmitters using solid rods or plates of carbon. It suffered very seriously however from what is now termed *packing*. The transmitter must necessarily be placed in a vertical position to ensure that the granules shall always be in contact with the diaphragm. The effect of working the instrument is to cause the granules to settle down into the smallest possible compass and, when the instrument has been in use for any length of time, the granules become closely packed at the bottom of the diaphragm and correspondingly loose at the top. The part of the diaphragm where the motion under the influence of sound waves is greatest is at the centre. Round the outer edge of the diaphragm the movement is inappreciable and consequently the granules at the edge remain practically in the same condition as regards their resistance of contact. Further, at the bottom, the granules are very tightly packed and form a partial short circuit across the central part. The contact resistance of the granules between the front and back plates at the centre of the diaphragm is varied to a very considerable extent, but the resistance of the granules round the edges, particularly at the bottom, does not vary and therefore the total variation of resistance of the instrument is considerably reduced.

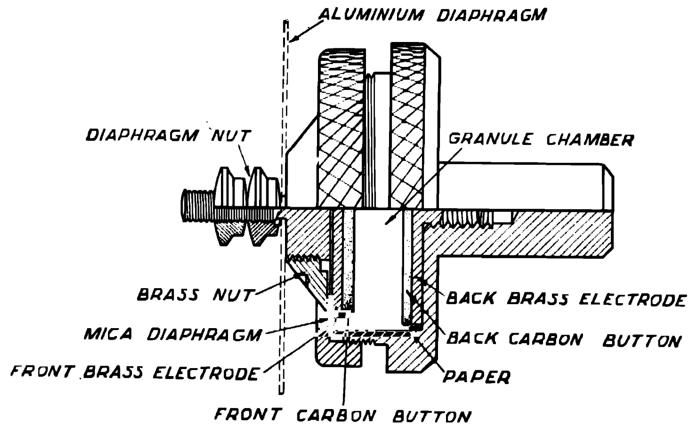


FIG. 31. ENLARGED VIEW OF GRANULE CAPSULE OF THE SOLID-BACK TRANSMITTER

The Hunnings transmitter has been very considerably developed during the past 45 years, but granular carbon is still retained as the basic medium for telephone transmitters. Carbon can be readily produced at low cost in the form of small granules. It is infusible, does not oxidize and its high specific resistance makes it eminently suitable for use in a variable-resistance transmitter. Moreover, the resistance decreases with increase of mechanical pressure and with increase of temperature. Both these characteristics assist to some slight extent in the operation of the instrument.

The Solid-Back Transmitter. This transmitter (P.O. Transmitter No. 1) was for many years the standard transmitter for telephone instruments and is, in fact, still used to some extent in other countries. It was designed by Anthony C. White of the Research Staff of the Western Electric Co. Although the microphones of this type, as made by the various manufacturing companies, differ slightly in detail, there has been little change in principle.

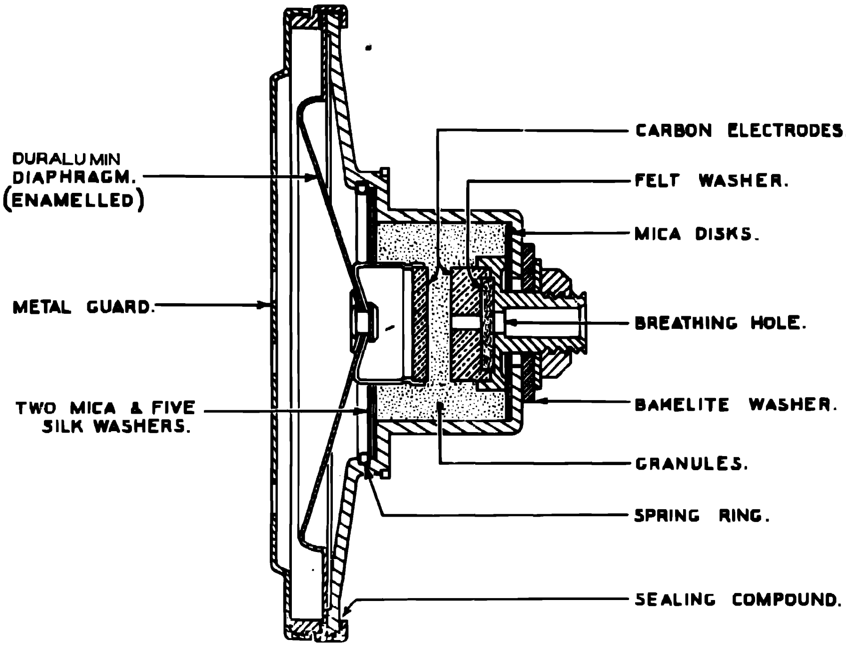


Fig. 32. Section of Modern Inset Transmitter
Transmitter inset No. 13.

The electrical portion of the transmitter (Figs. 30 and 31) consists of a circular granule chamber lined with shellacked bond paper, and rigidly fixed to a metal bridge-piece. The rear carbon button is copper-plated on the back and soldered to an electrode of brass, while the front carbon button is similarly fixed to the front electrode, also of brass. The carbon buttons are highly polished on the surface in contact with the granules, and the granule chamber contains about $\frac{1}{2}$ g of carbon granules. The front electrode is carried on a very thin mica flange and is rigidly fixed to the centre of the aluminium diaphragm. The diaphragm itself is mounted loosely in a soft rubber seating and is not clamped firmly around the whole of its edge as is a receiver diaphragm. The rubber-tipped flat steel springs are for the purpose of damping out persistent vibration, the natural frequency of the diaphragm and its electrode being about 1200 c/s.

Movement of the aluminium diaphragm is communicated to the granule chamber by means of the piston action of the front electrode with its flexible mica support. Adjustment of the transmitter can be carried out with the aid of the clamping screw, whilst the tension on the damping springs needs careful adjustment to obtain the best results.

The resistance of a microphone when no sound waves are impinging upon the diaphragm is known as the *quiet resistance*, in contradistinction to the *speaking resistance* when sound waves are falling upon the diaphragm. The quiet resistance of the solid-back microphone varies with the angle at which the microphone is tilted and with the current flowing through it. A typical figure is 40 Ω with a current of 80 mA. For efficient operation, the direct current in the transmitter should not fall below 25 mA.

Modern Inset Transmitter. The latest type of transmitter (Transmitter Inset No. 13) standardized by the Post Office is shown in Fig. 32. The transmitter is of the *inset* type and is designed primarily for use in hand microphones. The electrodes of the transmitter are totally immersed in the granules which flow around them in such a way that, in whatever position the transmitter is held, the required pressure of the granules on the surface of

the electrodes is maintained. Thus whatever the position of the transmitter the resistance is kept within the required limits, and the mechanical reaction, by which the vibrations of the diaphragm are converted into variations of pressure on the granules, remains substantially constant. In some of the earlier types of transmitter, if the faces of the electrodes approach a horizontal position, the pressure between the granules and one or other of the electrodes is much reduced even if the granules do not actually leave the electrode. The result is that transmission suffers badly and "frying" is set up. The *immersed electrode* principle has now been established as the most satisfactory arrangement for a transmitter, particularly when the transmitter is used in conjunction with hand microphones.

The diaphragm and its moving electrode are considerably simpler than in previous transmitters. The effective vibrating mass of the moving parts amounts to only 0·8 g as compared with 8·3 g in the solid-back transmitter. The diaphragm is made of thin, but very rigid metal, in the shape of a cone. The walls of the granule chamber are enamelled to prevent electrical contact with the granules, whilst the latter are held in position by a series of five silk and two mica washers which effectively prevent the escape of granules but at the same time offer a minimum resistance to the movement of the piston. The mica diaphragm and the damping springs of the solid-back transmitter are entirely eliminated, and the freedom of the moving system, together with the substantial reduction of its mass, result in an appreciable improvement in the articulation efficiency of the instrument. In the original inset transmitter protection against moisture entering from the mouthpiece took the form of a flexible membrane of oiled silk stretched across the front of the diaphragm. Although this proved to be adequate in the majority of situations, trouble was experienced on busy call offices, especially in damp situations where the membrane was sometimes found to soften, thus prejudicing the efficiency of the inset and in some cases producing corrosion of the diaphragm. Numerous substitutes for the silk membrane were tried out with only partial success, and in the latest transmitter it is eliminated entirely, protection against dampness being obtained by enamelling the front surface of the diaphragm itself. In addition a special cement is used to seal the spun joint around the edge of the case so that the front of the inset is hermetically sealed. The efficiency of this seal is checked before acceptance of an inset from a contractor by immersing the inset face downwards in water and applying air pressure equivalent to 10 in. of water through the "breathing hole" in the back electrode. This breathing hole is necessary to provide for equalization of air pressure in the granule chamber whenever changes occur in temperature and atmospheric pressure. Originally the breathing hole was provided in the diaphragm itself, but the abolition of the oiled silk membrane and the sealing of the diaphragm have necessitated the removal of the hole to the back of the transmitter where access to the granule chamber is obtained via the rear electrode. A felt pad is inserted behind the back electrode to prevent the egress of granules from the chamber.

The granules are of hard burnished carbon of selected grain, and uniformity of performance is obtained by the accurate spacing of the opposing electrodes and careful adjustment of the quantity of granules. After assembly and filling, the transmitter case is permanently closed by a spinning operation. This does, of course, exclude the possibility of repairing the transmitter without special appliances, but the adjustment of such an instrument is in any case a factory operation and not one suitable for carrying out in the field.

A perforated metal guard protects the diaphragm, and the holes in the mouthpiece of the telephone are arranged to "break joint" with those in the metal guard so that when the transmitter is in position the diaphragm is protected against any possibility of mechanical damage. The transmitter is suitable for use on all existing transmission systems and will perform satisfactorily with an energizing current of from 30 to 200 mA. Its volume efficiency is some 3 db better than that of the solid-back transmitter.

· Theory of the Carbon Microphone. Although the carbon microphone was first introduced about the year 1880, until very recently no fully comprehensive theory of its operation had been formulated. Some of the early inventors held the view that a microscopical air film between the granules was responsible for the microphonic action, whilst others contended that the small arcs set up between the granules or the local heating produced the effect. Another and more accepted theory was that the microphonic action depended upon the area of contact of the carbon granules. During the past ten years considerable work has been done on the problem in both America and this country. Drs. Goucher and Haynes of the Bell Laboratories have carried out an exhaustive examination of single carbon granules in contact. Dr. Goucher concludes that the surfaces of carbon particles are microscopically rough, and may be considered as spheres covered with innumerable hemispherical hills

(Fig. 33). When two such surfaces are brought together under pressure from the transmitter diaphragm, both the number of the hills in intimate contact and the contact area between hills varies through the deformations of the carbon surface under pressure. These deformations of the carbon surface are temporary only, since the carbon is not normally stressed beyond its elastic limit. This straightforward theory does not, however, explain various phenomena such as the high degree of amplitude distortion, etc., which is observed with practical transmitters. Mr. D. McMillan of the Post Office Research Station shows that whilst the theory of Dr. Goucher is probably correct for carbon granules continuously in contact, all the observed characteristics indicate that the main microphonic action is due to the individual granules separating from one another and "bouncing about" under the influence of an applied sound pressure. Mr. McMillan has supported this theory with theoretical calculations on the mechanical forces to which granules in a transmitter are subjected. The calculations have, in turn, been verified by the production of experimental transmitters of greatly increased performance. It is probable, therefore, that considerable advances in transmitter design, particularly with regard to improved articulation efficiency, will occur in the next few years.

Characteristics of Carbon Microphones. The carbon microphone probably introduces more distortion into a telephone system than any other single component. It is, however, unlikely to be superseded for some considerable time due to its very high sensitivity as compared with other known transmitters. A typical output frequency curve for an Inset No. 13 is given in Fig. 34. Although this transmitter has a considerably better performance than previous productions, the response varies considerably at different frequencies. There is a double resonance at about 1800 c/s and a smaller resonance at about 2800 c/s. These resonant points vary with the intensity of the sound pressure and are modified appreciably when the inset is fitted into a handset. The main resonance under the latter conditions occurs at approximately 1200 c/s. The unequal output at different frequencies produces the main cause of distortion, i.e. frequency distortion. The carbon microphone also introduces a very large degree of amplitude distortion, i.e. a change in the value of sound pressure is not followed by a proportional change in the electrical output. As mentioned above, a change in sound pressure modifies the resonant points of the characteristic, and hence the change in output resulting from a given change of applied sound pressure varies with the frequency of the sound. At high values of sound pressure the resonances are appreciably "damped." Fig. 35 shows the output of a typical inset at 1800 c/s with differing values of applied sound. It will be noted from this curve that when the sound pressure is 0·094 dynes/sq cm the a.c. output is 0·00078 V. If the sound pressure is increased by 10 db the output voltage increases by approximately 10 db. When the level of the sound pressure is increased to 20 db above the first value, the corresponding increase of electrical output is about 24 db. Similarly, with a sound pressure increase of 50 db, the electrical output is approximately 70 db, i.e. the electrical output is 100 times the proper value for distortionless reproduction.

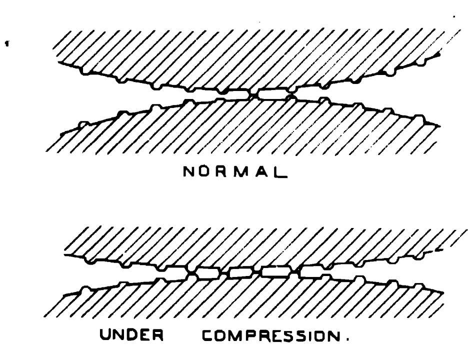


FIG. 33. DIAGRAMMATIC CROSS-SECTION OF TWO CARBON GRANULES IN CONTACT

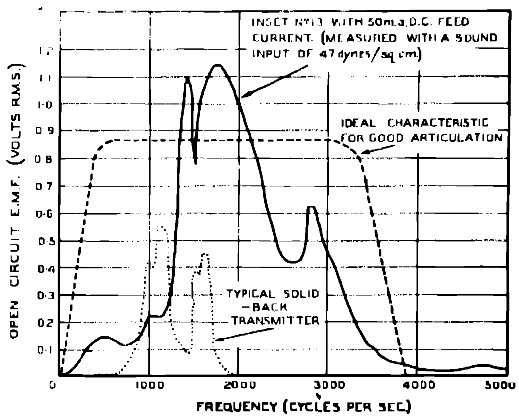


FIG. 34. ELECTRICAL OUTPUT OF AN INSET TRANSMITTER AT VARIOUS FREQUENCIES

The d.c. polarizing current also affects not only the voltage output but also to some extent the shape of the characteristic. As the polarizing

current is increased, the output rises gradually at first but increases more rapidly towards the upper limit. Apart from the primary distortions, the carbon microphone introduces harmonics and sub-harmonics which are not present in the applied

If, now, a sound wave of certain intensity changes the quiescent resistance by a peak value equal to $x\ \Omega$, the alternating resistance change can be expressed by $x \sin \omega t$, where $\omega = 2\pi f$ (assuming perfect linearity).

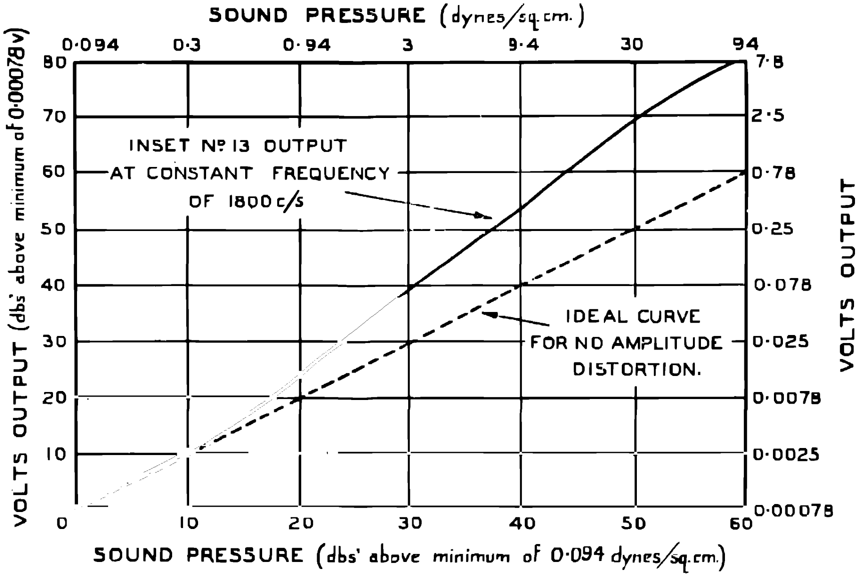


Fig. 35. Output of an Inset Transmitter with Various Sound Pressures

sound wave. The second harmonic (twice frequency) and the second sub-harmonic (half frequency) are the most important, and the latter (which has a maximum value at an input frequency of about 1800 c/s) produces the maximum distortion to articulation owing to the high sensitivity of receivers at about 900 c/s. Another effect of the "non-linear" response of the carbon microphone is the production of extraneous frequencies due to the intermodulation of two simultaneous inputs at different frequencies.

Theoretical Considerations. When a pure sinusoidal sound wave is applied to a carbon microphone, the inward displacement of the diaphragm is less than the outward displacement due to the greater "stiffness" of the moving system when the granules are compressed. This non-linearity of the carbon microphone is largely responsible for the production of extraneous frequencies. It is interesting to note, however, that apart from practical considerations the production of harmonics is inherent in *any* form of variable-resistance transmitter.

If a constant voltage E is applied to a transmitter of $R\ \Omega$ quiescent resistance then the steady direct current is given by:

Current in transmitter $= I = E/R$ (Ohm's Law)

Thus, the effective resistance of the transmitter at any instant $= R + x \sin \omega t$,

and the instantaneous current $= i = \dfrac{E}{R + x \sin \omega t}$

$$= \frac{E}{R\left(1 + \frac{x}{R} \sin \omega t\right)}$$

$$= \frac{E}{R} \times \frac{1}{1 + \frac{x}{R} \sin \omega t}.$$

The first factor (E/R) is the quiescent current and is constant. The second is the alternating component of the current. It can be shown algebraically that any fraction in the form of $1/(1 + a)$ can be expanded into an infinite series:

$1/(1 + a) = 1 - a + a^2 - a^3 + a^4 - a^5 +$ etc., to infinity.

Expanding the alternating component:

$$\frac{1}{1 + \frac{x}{R} \sin \omega t} = 1 - \frac{x}{R} \sin \omega t + \left(\frac{x}{R}\right)^2 \sin^2 \omega t - \left(\frac{x}{R}\right)^3 \sin^3 \omega t + \left(\frac{x}{R}\right)^4 \sin^4 \omega t, \text{ etc.}$$

Now, it can be shown mathematically that $\sin^2\omega t$, $\sin^3\omega t$, $\sin^4\omega t$, etc., contain frequencies of 2ω, 3ω, 4ω, etc., respectively. Thus, the resulting alternating current consists of the wanted fundamental ($\sin \omega t$) plus harmonics of all frequencies up to infinity. The factor x/R must necessarily be less than one (it is usually about 1/50) and hence $(x/R)^2$, $(x/R)^3$, $(x/R)^4$, etc., are of rapidly decreasing magnitude. In practice, therefore, harmonics beyond the third are of little significance.

Receivers. All commercial telephone receivers are of the electromagnetic type with a flexible iron diaphragm. Basically, the receiver consists of an electromagnet mounted in close proximity to the diaphragm so that, when alternating currents of speech frequency are passed through the windings, the varying magnetic pull on the diaphragm causes it to vibrate in accordance with the received currents. The receiver does, however, differ from a normal electromagnet such as a relay in two important respects. Firstly, the electrical energy available is extremely small (usually less than $\frac{1}{10}$ μW), and the design must ensure that as much of this energy as possible is converted to sound. Secondly, the electrical input consists of a wide range of frequencies which must be faithfully reproduced in the movement of the diaphragm.

Fig. 36 shows the general arrangements of a receiver. The pull on the diaphragm depends upon the magnetic flux density in the air gaps, and hence the design must aim for a maximum change of flux for a given change of current in the coils. The magnetic circuit is therefore made as short as possible and of high permeability material to obtain a minimum reluctance. The largest part of the reluctance is, of course, in the air gaps between the pole-pieces and the diaphragm, and the distance between the two is reduced to the minimum which will just avoid physical contact during operation of the receiver. It is usual to "polarize" a receiver by the introduction of a permanent magnet as a yoke to the two short pole-pieces. The purpose of this polarization is discussed later. It will be noted that the coils are wound on cores of thin but wide iron rather than the more usual round material. The thin material minimizes the eddy current losses in the core by offering a longer and higher resistance path. (The principle is the same as the lamination of transformer cores.) The flat cross-section also avoids saturation in the very thin diaphragm by providing a better distribution of flux through it. Moreover, the yoke of high retentivity steel introduces a high reluctance in the magnetic circuit, and the wide pole-pieces provide an alternative air path of large cross-section at the rear of the coils for the alternating fluxes.

As the diaphragm moves under the action of the exciting currents, it cuts the intense field of the permanent magnet and e.m.f.s are thereby induced into the diaphragm. These e.m.f.s in turn produce circulating currents, the magnetic field of which tends to oppose the initial movement of the diaphragm (Lenz's Law). To minimize this damping effect, the diaphragm is made of some material such as "Stalloy," which has a high resistivity in addition to a high permeability. The magnetic

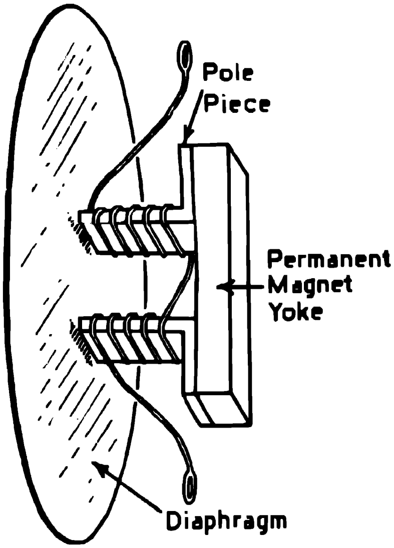


FIG. 36. GENERAL ARRANGEMENTS OF AN ELECTROMAGNETIC RECEIVER

forces on the diaphragm are so small that advantage is taken of its mechanical resonance to increase the volume of sound output. It is usual to design a diaphragm so that it has a natural frequency of vibration about the mean speech frequency, i.e. about 1000 c/s. Whilst this practice does of course introduce frequency distortion it nevertheless gives a very appreciable increase in efficiency at the frequencies most important in commercial speech.

Effect of Polarizing a Receiver. If a receiver is designed without a permanent magnet, and the circuit is arranged to avoid a direct current in the receiver windings, the only magnetizing force is due to the speech currents themselves. Not only is the resultant sound output small, but the diaphragm is attracted during each half-wave of voice-frequency current. The resultant sound output is therefore double the frequency (i.e. one octave higher) than the applied speech currents.

The tractive force or pull of any magnet is given by:

$$\text{Pull} = B^2 A / 8\pi$$

where B = flux-density in air gap
and A = area of pole face.

With a receiver of given design the pull on the diaphragm at any instant is directly proportional to the square of the flux-density. If b is the maximum value of alternating flux-density, and the frequency is ω radians per sec, then the flux-density at any instant (t) can be expressed:

$$\phi = \text{b} \sin \omega t$$

but the pull on the diaphragm is proportional to the square of the flux, i.e.

$$\begin{aligned} \text{Pull} &= (b \sin \omega t)^2 \\ &= b^2 \times \sin^2 \omega t \\ &= b^2 \times \tfrac{1}{2}(1 - \cos 2\omega t). \end{aligned}$$

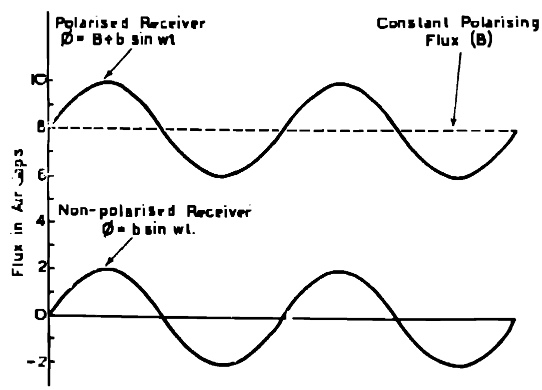
It is apparent, therefore, that the magnitude of the pull on the diaphragm is proportional to the square of the maximum flux-density (i.e. there is amplitude distortion) and the frequency is twice that of the applied current.

If now a permanent magnet is introduced, or if there is a polarizing direct current in the windings, the maximum flux-density is $(B + b)$ where B is the static flux. As before, the maximum pull is proportional to the square of the maximum flux-density,

$$\text{i.e. maximum pull} = (B + b)^2$$

The static pull is, of course, proportional to B^2, therefore the *change* in tractive force due to the alternating flux-density b is:

$$\begin{aligned} \text{Change of tractive force} &= (B + b)^2 - B^2 \\ &= B^2 + 2Bb + b^2 - B^2 \\ &= 2Bb + b^2. \end{aligned}$$



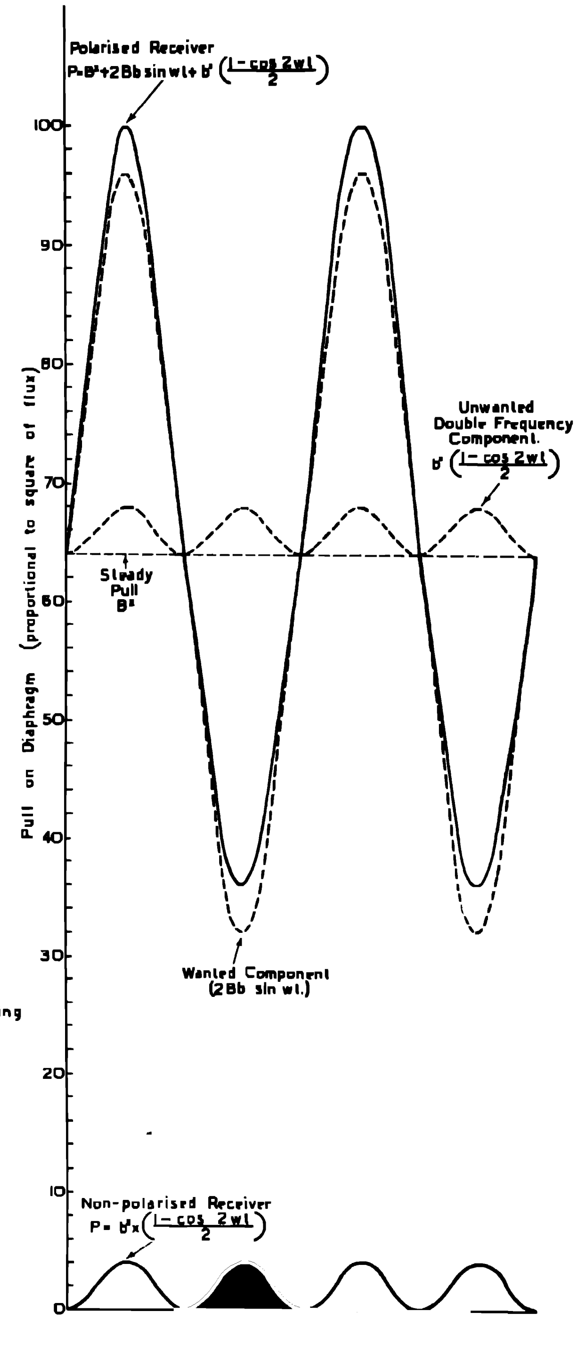


FIG. 37. EFFECT OF POLARIZING A RECEIVER

As before, the instantaneous value of a.c. flux is $b \sin \omega t$, and hence the instantaneous value of tractive force is:

$$2\,Bb \sin \omega t + b^2 \sin^2 \omega t$$
$$= 2\,Bb \sin \omega t + \tfrac{1}{2}b^2(1 - \cos 2\omega t)$$

The first term represents a tractive force of the correct frequency and of magnitude proportional to twice the product of a.c. and d.c. magnetization. The second term is an unwanted second harmonic, the value of which depends upon the square of the a.c. magnetizing force. Thus the introduction of a permanent magnet produces an output of the correct frequency and of much greater magnitude. The second harmonic is still present, but when the d.c. magnetization is large in comparison with the a.c. magnetization, the harmonic forms only a small part of the total output. Fig. 37 shows in graphical form the effect of polarizing a receiver, and illustrates clearly the large gain of output even when the polarizing flux is only four times that of the peak a.c. flux. (In practice the static flux is very much greater.) The slight lack of symmetry in the curve for the polarized receiver due to the presence of the second harmonic will be noted.

Bell Receiver. The receiver illustrated in Fig. 38 is of a type which has been much used in the past, although the advent of the hand-microphone has now made this type of receiver obsolescent. The permanent magnet consists of two half-round bars of tungsten steel yoked together by a steel screw. The L-shaped soft iron pole-pieces are screwed to the ends of the bar magnet by screws passing through the brass cup-shaped inner case. Each of the coils is wound with some 600 turns of single silk-covered or enamelled wire to a resistance of 30 Ω, giving a total resistance for the receiver of 60 Ω. An alternative form of magnet is a horseshoe type bent out of a single bar, the rounded end being bevelled to accommodate the strain cord.

The diaphragm is of stalloy, which is an alloy of about 97 per cent iron, 2·75 per cent silicon, and smaller quantities of manganese and carbon. This alloy has a high permeability and a high resistivity, and, in consequence of the reduction in eddy current and hysteresis losses, the receiver is more efficient than if the diaphragm were of soft iron.

The ends of the pole-pieces and the seating for the diaphragm are ground perfectly level, with a clearance of 13 mils between the ends of the pole-pieces and the diaphragm. The pole-piece ends are lacquered after the grinding operation has been completed to prevent rusting.

The magnet carrying the inner case fits into an outer case of brass, coated with ebonite on the outside surface, whilst the moulded ear-piece screws on to the outer case and clamps the inner case and diaphragm in position. Three shallow recesses in the outer rim of the ear-piece are provided, so that, should the receiver have been placed cap downwards on a table and forgotten, a considerable amount of noise will result when the howler is applied from the exchange. The resonance period of the diaphragm is about 940 per sec., and the

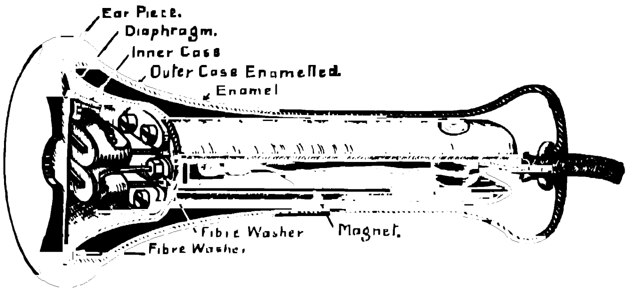


FIG. 38. PARTIAL CROSS-SECTION OF TYPICAL BELL RECEIVER
Receiver Bell, No. 1A

impedance of the 60 Ω Bell receiver at a frequency of 800 c/s is about 200 Ω.

The Modern Inset Receiver. A more modern type of receiver (No. 1L) as used in the hand-microphone is illustrated in Fig. 39. (See also Fig. 219.) The body of the receiver is a light aluminium die-casting and is secured to the moulded handset by two screws which also provide the electrical connexions to the receiver. Each of the two coils is wound with approximately 1000 turns of silk-covered or enamelled wire, and has a nominal resistance of 40 Ω (80 Ω for both coils). The pole-pieces are provided with U-shaped lugs which are screwed to the case to clamp the permanent magnet and the whole coil assembly. After assembly, the pole-pieces are ground to give a clearance of 12 to 14 mils to the diaphragm. A powerful blast of air is now applied to remove all particles of dust or iron and the whole interior is then sprayed with cellulose lacquer. The diaphragm is of Stalloy 9 mils thick, and is protected against rust by a coat of black varnish on both sides. The large centre hole of the earlier earcaps is now replaced by three smaller holes which prevent mechanical damage to the diaphragm.

The Equalized Receiver. As a result of recent research, a new receiver (No. 2P) has been introduced which has a volume efficiency comparable with the standard receiver (1L), but the quality of reproduction has been much improved by an increase in sensitivity at the higher frequencies.

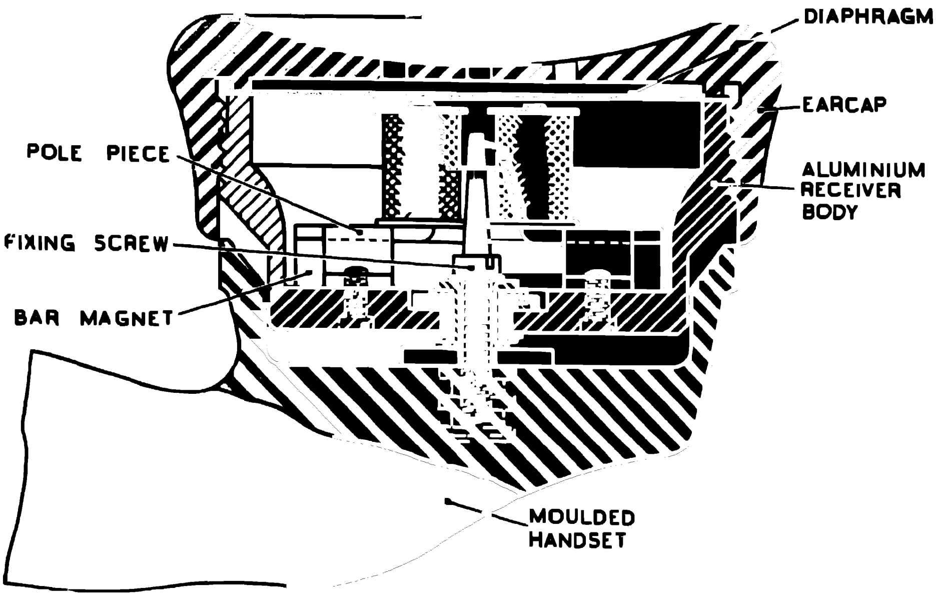


FIG. 39. CROSS-SECTION OF INSET RECEIVER IN HAND MICROPHONE
Receiver inset No. 1L.

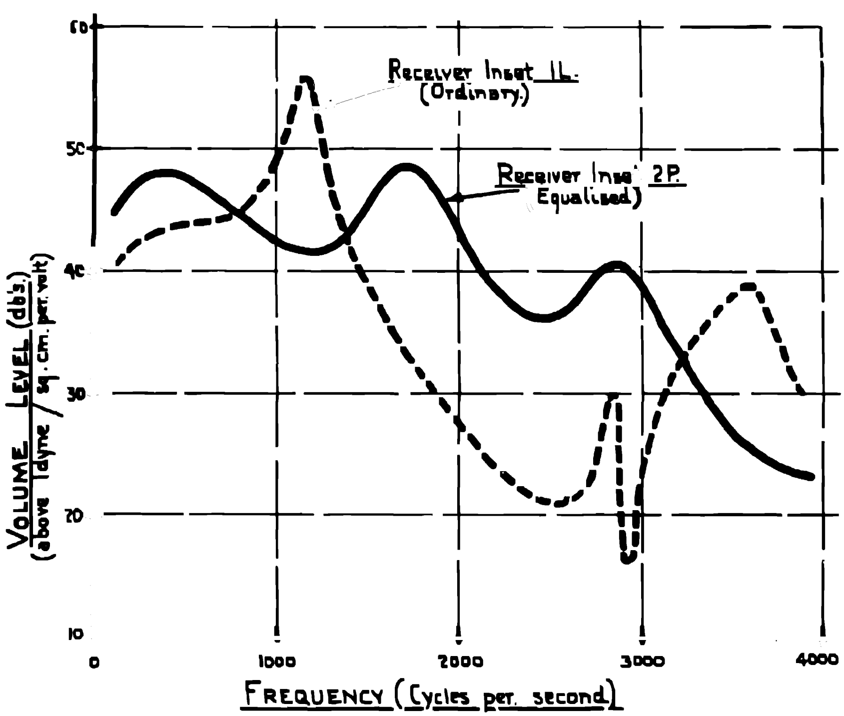


FIG. 40. RESPONSE CURVES OF EQUALIZED AND NON-EQUALIZED RECEIVERS

Fig. 40 shows typical frequency-response characteristics of the new equalized receiver and of the normal type. It will be noted that the curve for the new receiver is not only much flatter but that the output over the region of 1500 to 3000 c/s has been raised some 10–15 db above that of the old receiver. This increased efficiency over the upper part of the speech range is largely responsible for the improved performance, but the elimination of very sharp resonances also materially assists. In the receiver 1L, there is a very sharp peak of response at about 1100 c/s due to diaphragm resonance. The abnormal output level at this particular frequency produces a masking effect which renders inaudible tones of other frequencies, especially those in the higher part of the frequency range. The effect is particularly marked where the level of the masked frequency is much lower than that of the masking frequency.

In the new receiver the main resonance at about 1100 c/s has been replaced by careful acoustical design by three well-damped resonances suitably spaced throughout the full spectrum of commercial speech. Fig. 41 gives a sectional view of the receiver 2P. The diaphragm is lighter than the earlier design and resonates about 1700 c/s. The resonance is, however, considerably damped by the restricted air space on each side of the diaphragm. The back air space is itself a resonant chamber, and is connected to the larger volume behind the receiver through a small duct closed by a silk disc. The quality of the silk and the dimensions of the chamber and duct are adjusted to produce a second heavily damped response peak at about 300 c/s. The third peak at about 2900 c/s has been obtained by careful design of the ear cap in relation to the constants of an average ear. The small resonant chamber in front of the diaphragm is slightly conical in shape to give a uniform pressure distribution from the perifery to the centre, and the ear-cap holes (four in number) are concentrated near the centre. If the receiver is not held firmly to the ear, leakage in the outer resonant chamber (between the ear and ear cap) has the effect of producing a more marked resonance at some frequency below 600 c/s.

The introduction of diaphragm damping to equalize the output of a receiver tends to reduce the volume efficiency. To compensate for this in the receiver 2P, the magnetic circuit has been redesigned to obtain the optimum efficiency. The permanent magnet is of "Alnico" as in the receiver 1L, but the pole-pieces are constructed of a 36 per cent nickel-iron alloy which gives a good a.c. permeability coupled with a low eddy-current loss (the specific resistance is approximately six times that of iron). The diaphragm is thinner and lighter than usual for acoustical reasons, and compensation is made by the use of a very high

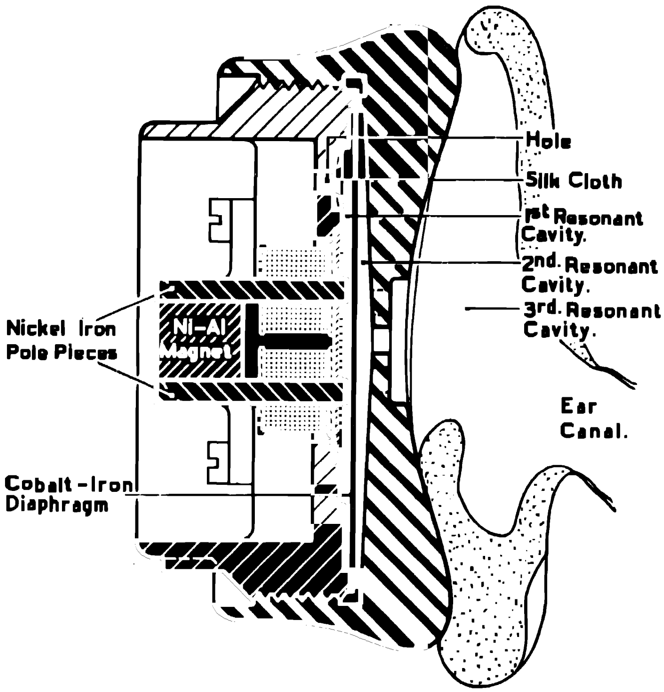


FIG. 41. CROSS-SECTION OF THE EQUALIZED RECEIVER
Receiver Inset No. 2P.

permeability cobalt-iron alloy (Permendur). The cross-sectional area of the pole-pieces is the maximum subject to practical considerations, and similarly the pole-piece/diaphragm air gaps have been reduced to the minimum safe limit.

The general arrangements of the receiver are similar to the 1L type. A receiver (Receiver Headgear 10A) for use with operators' headsets has also been introduced. It is fundamentally similar to the 2P type but has a bakelite frame instead of the die-cast aluminium frame in order to minimize weight.

Performance of Receivers and Transmitters. Until comparatively recently the performance of production samples and of new transmitter and receiver designs was determined by comparison on a volume efficiency basis with a standard transmitter and receiver. As a result of this method of comparison, defects of the standard components were perpetuated in new or modified designs. The

standard receiver for a time was the Bell receiver which had a pronounced mechanical resonance, and a correspondingly high output in the neighbourhood of 1000 c/s. New receivers compared with the standard Bell receiver therefore showed up badly on volume efficiency tests unless they too had a comparable mechanical resonance. The fallacy of this method of testing was realized some years ago, and in modern practice the performance of transmitters and receivers is determined purely by articulation tests. It has been found that the most satisfactory form of articulation testing is to transmit monosyllabic words such as dab, bad, lad, sab, etc., and to determine the percentage of correct results received by a listener. These monosyllabic words (logatoms) consist essentially of a starting sound (usually a consonant), a middle sound (usually a vowel), and a stopping sound. It is therefore possible to obtain a very accurate picture of the articulation efficiency by allocating three points for each word which is correctly received in its entirety, two points for a word which is two-thirds correctly received, and so on.

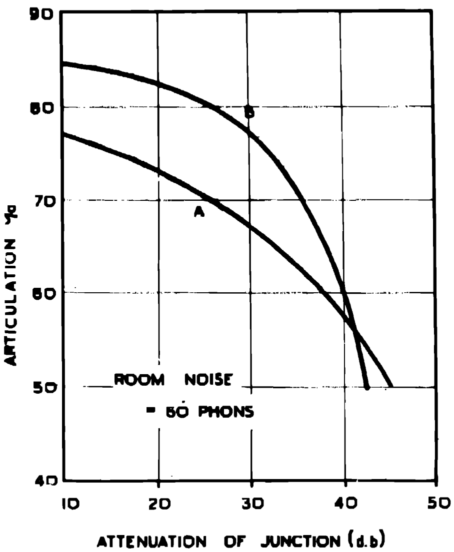


Fig. 42. Comparison of Articulation Efficiency
A = Transmitter No. 13 working to Receiver No. 1L.
B = Experimental transmitter working to Receiver No. 2P.

The articulation efficiency is measured with various degrees of attenuation between the transmitting and receiving instruments, and curves can then be plotted to show the variation of articulation efficiency with line attenuation. Room noise which is a normal condition during ordinary telephone usage has some effect on the articulation, and it is usual to carry out tests at a prescribed level of room noise, e.g. 60 phons. Fig. 42 shows a typical result of the variation in articulation as the attenuation between the transmitter and receiver is increased. Curve *A* shows the results of an ordinary inset transmitter (No. 13) working to a standard unequalized receiver (1L). Curve *B* shows the much higher articulation efficiency of a new type of experimental transmitter in conjunction with the equalized receiver (2P). The improvement is largely due to the better frequency response of the new receiver, although the new transmitter does raise the curve slightly. From these curves it can be seen that for a given articulation efficiency, e.g. 70 per cent, the use of the new transmitter and receiver enables an additional 10 db of attenuation to be introduced into the telephone network. Alternatively, for the same attenuation, say 30 db, the articulation rises from approximately 67 per cent to 77 per cent.

EXERCISES III

1. Explain how an alternating current of the same frequency as the incident sound can be produced by a carbon microphone.

What factors govern the magnitude of this current? (*C. & G. Telecommunications* (*Principles*) *I*, 1947.)

2. With the aid of a simple constructional sketch, describe the operation of a modern type of telephone receiver. State the reasons for the use of a permanent magnet, and explain why special steel is used for the diaphragm. (*C. & G. Telephony, Grade I*, 1946.)

3. Give a sectional sketch and a detailed description of a modern inset transmitter. (*C. & G. Telephony, Grade I*, 1941.)

4. Discuss the theory of operation of the carbon granule transmitter. In what ways does a carbon transmitter distort speech?

5. A sinusoidal current of speech frequency is passed through (*a*) a non-polarized and (*b*) a polarized receiver. Show graphically how the sound output varies in the two cases.

6. Describe a modern receiver in which the main resonance peak is damped out.

7. Explain how you would compare the articulation efficiencies of two receivers. In what form would you express the results of your test?

8. In what ways is a modern carbon transmitter better than the early transmitters employing granular carbon?

CHAPTER IV

RESISTORS, CONDENSERS, AND TRANSFORMERS

RESISTORS, condensers, inductors, and transformers are used to a considerable extent both in the signalling and in the transmission circuits of telephony. It is desirable, therefore, that the principles of design and the more common characteristics of these components should be considered at this stage before proceeding to a more detailed examination of transmission and signalling circuits. The various circuits of telephony are required to provide for a very wide range of electrical conditions. On the one hand, the circuit components are required to pass alternating speech currents of extremely small magnitude and of a very wide range of frequencies. In addition, there are at various parts of the circuit d.c. signalling currents of various values and a.c. signalling currents of low frequency. In some cases heavy direct currents are required for the operation of electromagnets, etc., and the components are required to withstand the consequent high voltages induced during the release of such electromagnets.

Resistors. A resistor is any component which is designed primarily to add ohmic resistance to a circuit. The value of any resistor in a d.c. circuit, can, of course, be readily calculated from Ohm's Law if the e.m.f. in the circuit, the required current, and the remaining resistance of circuit are known. Thus:

$$\text{Value of resistor} = \frac{E}{I} - R\,\Omega$$

where E = e.m.f. in the circuit (volts),
I = required current (amperes),
R = resistance of remainder of circuit (ohms).

Most resistors used in the signalling and switching circuits of telephony are of the wire-wound type and the resistance value is determined by the length and cross-sectional area of the conductor and by its specific resistance, i.e.

$$\text{Resistance} = l\rho/A\,\Omega$$

where l = length of conductor (cm),
A = cross-sectional area (sq cm),
ρ = specific resistance (ohms/cm cube)

To avoid an excessive length or an impracticably small diameter of wire it is necessary to employ a conductor of high resistivity. The earlier resistance materials, such as Platinoid, Manganin, and Eureka, have now been almost wholly superseded by nickel-copper and nickel-chrome alloys. The former has a lower specific resistance, but is more generally employed where the space factor is not critical. It is possible to weld nickel-copper to the connexion tags of a resistor. Nickel-chrome is better where the resistor may be required to withstand a high temperature and where the winding space is very limited. The following table shows the characteristics of the two materials as compared with those of copper.

Material	Specific Resistance microhms/cm cube	Temperature Co-efficient
Copper . .	1·78	0·0043
Nickel-chrome alloy (Ni 80%; Cr 20%)	105·0	0·0001
Nickel-copper (Ni 44%; Cu 56%)	48·0	negligible

The inductance of a wire-wound resistor is low due to the comparatively small number of turns, and its reactance at speech frequencies is usually insignificant when compared with that of the remaining components of the circuit. Hence most resistors are wound inductively for cheapness and simplicity of production. In those circumstances where a non-reactive resistance is necessary, the current is usually small and resistors of the carbon rod type can be employed. In the very few cases where a wire-wound non-inductive resistor is required, the wire is doubled back upon itself so that the magnetic field of each turn is neutralized by the equal and opposite current in the adjacent turn.

Fire Risk. A resistor always absorbs electrical energy whenever a current passes through it and this energy reappears in the form of heat. The rate at which heat is generated depends firstly upon the value of the resistance and secondly upon the *square* of the current in it, i.e.

$$\text{Heat generated} = I^2R.$$

It is therefore apparent that, if the current in a resistor is doubled, the heat to be dissipated is four times as great. It is of the utmost importance that circuits should be so designed that the heat generated in any resistor is *never* sufficient to raise

the temperature to such a value that there is a risk of fire. In considering this matter, it is not the normal current in the resistor which must be taken into account but the maximum possible current under *fault* conditions. In Fig. 43, for example, the *normal* current in the 100 Ω resistor is 100 mA, and

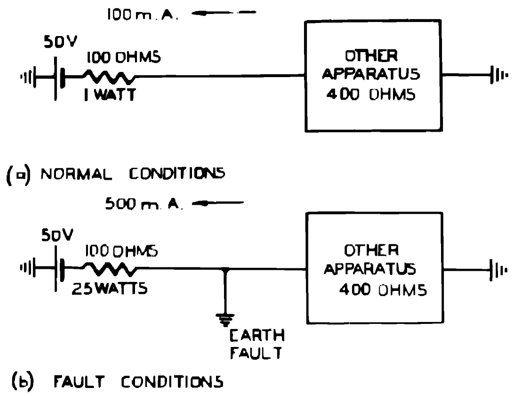


Fig. 43. The Effect of Fault Conditions on the Loading of a Resistor

the power absorbed is 1 W. If, however, an earth fault should occur between the resistor and the other apparatus, the current in the resistor increases to 500 mA, and the power now to be dissipated is 25 W. It is clear, therefore, that either the resistor must be capable of withstanding a continuous loading of 25 W without risk of fire, or alternatively a fuse which will blow at less than 0·5 A (i.e. of less than 0·25 A rating) must be inserted. Fuses of such very small size are generally impracticable on account of the fragility of the wire which must be used.

Fig. 44 shows the power dissipated by resistors of various values when subjected to a p.d. of 50 V directly across the resistor. If it is assumed that a fuse rated at 1 A (i.e. to blow at 2 A) is the smallest practical value, then, for the fuse to blow, the resistance must be less than 25 Ω. If the resistor is of 50 Ω, then it must be capable of withstanding a continuous loading of 50 W without risk of fire. Similarly, a resistor of 500 Ω must be capable of withstanding a loading of 5 W and so on. The graph also shows the maximum loading of various types of resistors which are described later. From this information it is possible to determine unsafe values of resistance when the resistor is subject to the application of a full 50 V. With the Resistor Coil No. 9, for example, values between 25 and 250 Ω are unsafe under these conditions. Where it is not possible to provide one single resistor of the required value owing to fire risk considerations, resistors of higher value may be placed in parallel until the loading of each is within safe limits. If, for example, in Fig. 43 the maximum loading of the available resistors was, say, 10 W, it would be necessary to provide three 300 Ω resistors in parallel to avoid the risk of fire. Under fault conditions the loading of each resistor would now be $8\frac{1}{3}$ W.

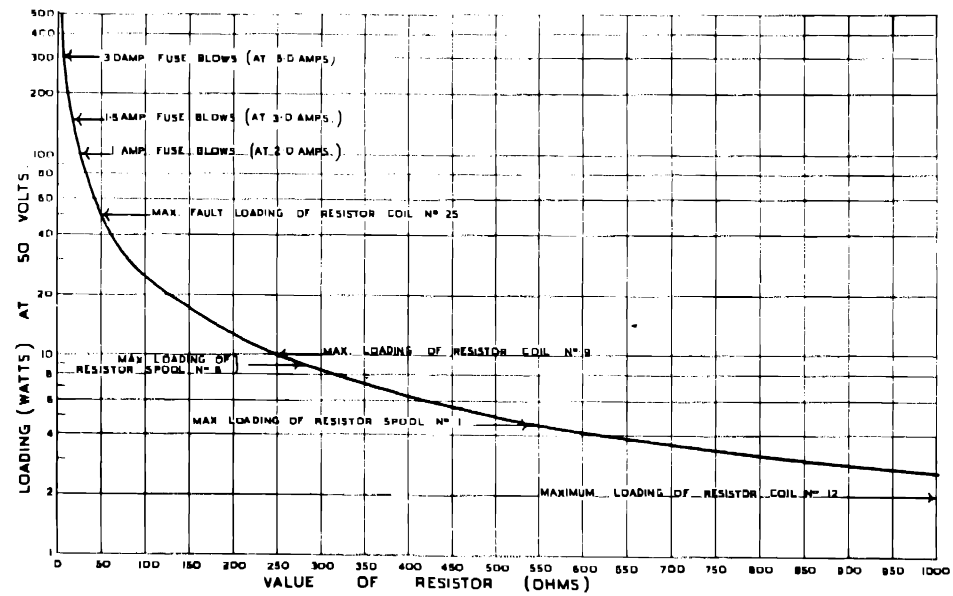


Fig. 44. Loading of Various Resistors at 50 V

It is apparent from the above that the choice of a resistor and its position in a particular circuit is a matter of some importance. The circuit conditions in some cases make it impossible to employ resistors which are intrinsically safe. In such cases reliance is placed upon the fact that the resistor will "burn out" before the temperature reaches an unsafe value.

Several different types of resistor have been standardized for use in various circumstances and are described in the following paragraphs. From the power dissipation aspect, a resistor should have as large a radiating surface as possible. The space factor is, however, important and a compromise must be made. In some of the earlier designs of resistor, fibre and other materials were used for the spool. Some of these materials gave off an inflammable gas when heated which has been responsible for several serious fires in telephone exchanges. Apart from the actual resistor design, care must be taken in mounting to avoid the setting alight of adjacent wiring (particularly wax-impregnated wiring).

Resistor Coil No. 12. This is the lowest rated resistor used in telephone signalling circuits and is illustrated in Fig. 45. The base of the resistor is a moulded bobbin 1 in. in diameter by ⅝ in. high which is wound to various standard resistance values up to 20 000 Ω. The winding is of silk-covered copper-nickel resistance wire which is soldered to the connexion tags of the bobbin. The unit is finished off with an outer layer of empire cloth through which the resistance designation label is visible. The No. 12 resistor is manufactured to within a tolerance of ± 2½ per cent of the nominal value and is specified to withstand a continuous loading of 2 W without deterioration. The fire risk loading depends to some extent on the mounting arrangements, but is generally in the order of 3 W. Specially selected coils under the code designation "12A" with a resistance tolerance less than ± 1 per cent may be obtained.



Fig. 45. Resistor Coil No. 12

Resistor Coil No. 9. This resistor is somewhat larger than the No. 12 type. The ceramic bobbin is cylindrical in form (Fig. 46) and is approximately 1 in. long × 1 in. in diameter. The bobbin is wound with enamelled copper-nickel resistance wire which is spot welded to phosphor-bronze connexion tags. The resistor is made in a large number of values up to 2000 Ω. Values up to 500 Ω are provided by means of a single layer winding, whilst higher values require the use of multiple layer windings. In all cases, there is an odd number of layers to facilitate the termination of the wire. The winding and welded connexions are finished with one coat of enamel or varnish.

The specified tolerance is ± 2½ per cent of the nominal resistance value, although somewhat larger margins are allowed for very low values (under 10 Ω). The single layer resistors (up to 500 Ω) have a maximum loading of 10 W, and the multiple layer coils of higher value have a rating of 8 W. They are required to withstand a 100 per cent overload for 15 min. without discernible deterioration. As for the No. 12 type, selected resistors (No. 9A) with an accuracy of ± 1 per cent are available for special purposes.

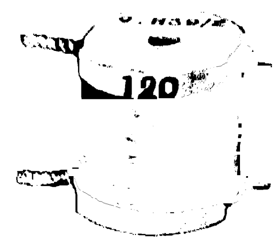


Fig. 46. Resistor Coil No. 9

A variation of the No. 9 type resistor has recently been developed (Resistor Coil No. 25) which is capable of dissipating up to 50 W under fault conditions. The bobbin is perforated to obtain maximum cooling and the winding is vitreous enamelled to withstand the very high temperature. Extreme care must be taken in the mounting of the resistor to avoid the risk of igniting adjacent wiring or apparatus.

Resistor Spool No. 1. Fig. 47 illustrates an obsolescent type of resistor which is still in fairly extensive use on older equipment. The bare nickel-silver resistance wire is wound on a flat micanite sheet and protective sheets of the same material are placed on each side of the winding. The whole assembly is clamped by means of brass strips which are extended to provide connexion tags and a means of mounting the resistor. The design provides a large surface area for heat dissipation and the resistor is rated to carry a maximum continuous loading of 4·5 W. This type of resistor is costly to manufacture and is very uneconomical of mounting space unless the resistors of a number of circuits are dissociated from other equipment and are mounted together as a strip of resistors.

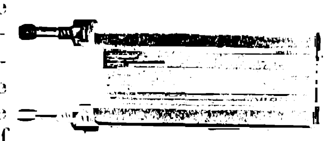


Fig. 47. Resistor Spool No. 1

The necessity of providing insulating bushes in the mounting holes is a further disability.

Resistor Spool No. 6. Fig. 48 shows a very small type of resistor specially designed to save mounting space by fixing direct to the tag of a condenser or other piece of apparatus. The resistor is approximately 0·65 in. long by 0·3 in. diameter and is made in various values up to and including 200 Ω. The resistance wire is wound on a ceramic bobbin to the

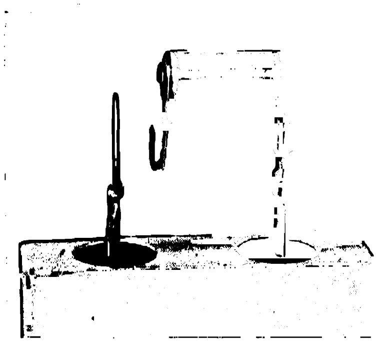


FIG. 48. RESISTOR SPOOL NO. 6
Mounted on condenser.

required value and the whole winding is then covered by a coloured vitreous enamel. The accuracy is ± 10 per cent of the rated value and the maximum safe loading is in the order of 9 W. The No. 6 type resistor is often used in conjunction with a condenser for magnet spark-quench circuits.

Carbon Resistors. Resistors in which the essential element is a rod of a semi-conducting material are becoming increasingly used in the circuits of telephony where high resistance values coupled with comparatively low power dissipation are required. There are two main types of resistor:

(*a*) Those where the resistance element is a solid rod of a high resistance material, usually a mixture of carbon and graphites bound by some form of resin.

(*b*) Those where the conducting medium is a surface film of carbon on a non-conducting rod or tube.

Both methods are very extensively employed, although in Great Britain the surface conduction type is probably the more common. In some cases the carbon or carbon-coated element is inserted in an outer protecting tube (the insulated type of resistor), but when the maximum heat dissipation is required a non-insulated type, i.e. without the outer tube, is provided. The wattage rating of a carbon resistor is determined by its size. In the Post Office four main ratings have been standardized, e.g. 2·5, 1, 0·5, and 0·25 W. The largest resistor has a total length of some 2½ in. and a diameter of almost ⅜ in., whereas the 0·25 W type is only about ½ in. long by approximately ⅛ in. diameter. Owing to the small size and the high resistance values of carbon resistors, it is not practicable to mark on the resistor itself the ohmic value of the component. A colour scheme has therefore been adopted internationally. In this scheme certain colours are used to represent specific numbers, thus:

Black represents		0	Green represents		5
Brown	,,	1	Blue	,,	6
Red	,,	2	Purple	,,	7
Orange	,,	3	Grey	,,	8
Yellow	,,	4	White	,,	9

Each resistor is so painted that the colour of the body of the resistor indicates the first significant figure of the resistance value. The colour of the end of the resistor indicates the second significant figure, whilst the colour of the centre signifies the number of 0's following the second significant figure. For example, a resistor with a purple body and a green end marking together with a red centre band or spot has a nominal value of 7500 Ω. Further colour code conventions are utilized to indicate the resistance tolerances from the nominal value, i.e.:

A gold spot on one end indicates		± 5 per cent.
A silver spot on one end	,,	± 10 per cent.
No special marking	,,	± 20 per cent.

It is difficult to ensure very close uniformity of resistor of the same nominal value during the manufacturing processes. Resistors having ± 20 per cent variations from the nominal value are sufficiently accurate for a large number of practical conditions, but where a greater accuracy is required resistors are specially selected from each batch.

Other Resistors. There are various other types of resistor used in telephony which do not warrant detailed description in this volume. Apart from the wire-wound and carbon type of resistors already considered, use is sometimes made of resistance lamps where a high dissipation of power is required. In other circumstances resistors are required which will increase rapidly in value as the current through them rises.

Non-linear resistors have been very considerably developed in the last few years and increasing use is being made of them in the transmission and signalling circuits of telephony. The metal rectifier is basically a resistor of asymmetrical conductivity, i.e. its resistance in one direction is appreciably different from that in the other direction, and the value of the resistance is controllable over a wide

ange by adjustment of the polarizing e.m.f. Many examples will be found in following chapters of the use of metal rectifiers which have in some cases completely revolutionized circuit design technique. In addition to the selenium and copper-oxide metal rectifiers, certain other materials have been produced recently which have a resistance which varies inversely with the applied voltage but which is independent of the direction of the voltage. Such resistors are sometimes known as *symmetrical varistors* to distinguish from *asymmetrical varistors* —e.g. copper-oxide rectifiers.

Atmite. A material known under the trade name of Atmite is an interesting example of a non-linear resistance material. Atmite is a silicon-carbide compound which is mechanically very tough and can be made into the form of discs with thicknesses suitable for various requirements. The discs are heat fired at a high temperature and are both electrically and mechanically stable. The current passed by an Atmite disc increases approximately as the fourth power of the applied voltage. A disc of 1 in. diameter and $\frac{1}{8}$ in. thickness, for example, has a resistance somewhat greater than 100 000 Ω when the applied voltage is 100, but when the voltage is increased to 400, the resistance decreases to some 600 Ω. A 1 in. disc will dissipate some 2 W of electrical energy. Atmite, in common with most of the other silicon-carbide compounds, requires a high voltage for its operation, and hence it is possible that it may be used in the future for magnet spark quench circuits or for lightning arrestors.

Copper-Oxide Rectifier. The copper-oxide rectifier is based on the discovery in 1926 that the conductivity of an oxide coated copper plate depends upon the direction of current flow. The modern type of copper-oxide rectifier consists of a series of discs of highly refined copper which are heated in air to a temperature of about 1000°C. A layer of cuprous oxide (Cu_2O) is thus formed on the surface of the disc. After annealing and cooling, the discs are treated with acid to remove an outer film of black cupric oxide (CuO) thereby exposing the bright red cuprous oxide surface. This surface is now painted with colloidal graphite and allowed to dry. A soft metal plate (the counter electrode) is now pressed against the graphited copper-oxide surface to form the complete element,—the graphite film ensuring intimate contact of the two electrodes. The elements are finally mounted under pressure on a central spindle to form a complete rectifier unit. A cross-section of a copper oxide rectifier element is shown diagrammatically in Fig. 49. The thicknesses of the cuprous oxide and graphite films are of course exaggerated for clarity.

The exact theory of operation is not yet fully established, but there is strong evidence of the presence of a thin film or "barrier" layer of electric charges between the copper and cuprous oxide surfaces. This film normally behaves as a highly insulating layer, but when a potential is applied to the element there is a movement of electrons through the layer. The different molecular struc-

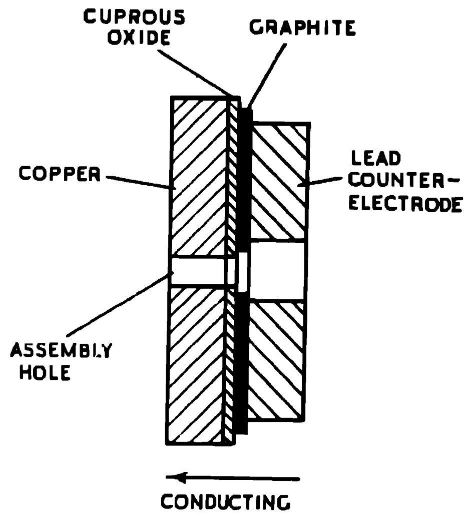


FIG. 49. DIAGRAMMATIC CROSS-SECTION OF COPPER-OXIDE RECTIFIER ELEMENT

tures of the copper and cuprous oxide appear to permit a much more ready flow of electrons from the copper to the oxide than in the reverse direction.

Typical voltage/current characteristics of a copper-oxide rectifier are shown in Fig. 50. It will be seen that a small voltage in the forward (conducting) direction results in a very large current flow, whilst in the reverse (non-conducting) direction a large applied voltage produces only a very small current. It is apparent that, if an alternating voltage is applied to the rectifier, the current during the positive half-cycle is large whilst during the negative half-cycle the current is, by comparison, negligible. (In Fig. 50 the scale for the reverse current is greatly magnified to make the curves visible.) Apart from its use as a simple rectifier of a.c., the metal rectifier has many other applications, which depend upon its peculiar resistance characteristics.

Fig. 51 shows the change of d.c. resistance as the applied voltage varies. With a negative voltage applied to the rectifier the resistance is upwards of 20 000 Ω/sq cm of element with a maximum resistance at about −2 V. The resistance characteristic is substantially flat (i.e. the rectifier behaves

as a linear resistance) between about −1·5 V and −3 V, but as the voltage is decreased to zero the resistance commences to fall. If the voltage is now reversed, the resistance falls very rapidly indeed until a positive voltage of some 0·5 V is reached.

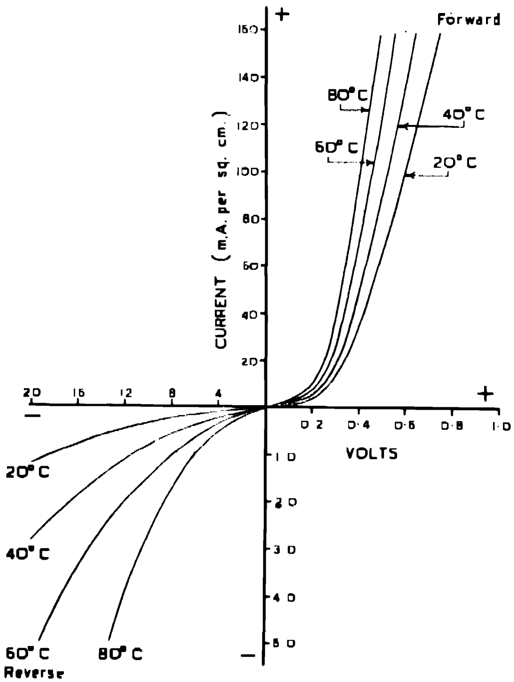


Fig. 50. Voltage/Current Characteristics of a Copper-oxide Rectifier Element

Note that the scale for the reverse current is magnified to make the curves visible.

As the positive voltage is further increased the characteristic flattens out to give a steady resistance in the order of 6 Ω/sq cm. By a slight change in the biasing e.m.f., therefore, a rectifier can be made to change its impedance to speech currents from a high to a very low value. Similarly, the rectifier can be used as a speech voltage limiter by so arranging the bias that the higher peaks of voltage modify the bias to the point of inflexion.

It is important that a copper-oxide rectifier should never be worked at a high temperature (above about 55°C). The curves of Fig. 50 show how the conductivity increases (and the resistance decreases) as the temperature rises. The energy dissipated by the rectifier depends directly upon the value of its resistance and also upon the *square* of the current through it (I^2R). Any decrease of resistance due to a rise in temperature may therefore produce such an increase of current that the temperature is still further increased. Normally, other apparatus of high resistance is in series with the rectifier for currents in the forward direction, but often the full battery voltage is applied to the rectifier in the reverse direction. Hence the possibilities of a rise in current due to a decrease in rectifier resistance are much more likely in the reverse than in the forward direction. Great care must be taken in circuit design to avoid overload of metal rectifiers, particularly in the reverse direction. Apart from the above, continuous working at high temperatures produces in time a permanent increase in the forward resistance and a reduction in the reverse resistance.

When rectifiers are used in circuits carrying frequencies above the audio range, allowance must be made for the high capacitance. The capacitance of a single element is in the order of 0·02 μF/sq cm

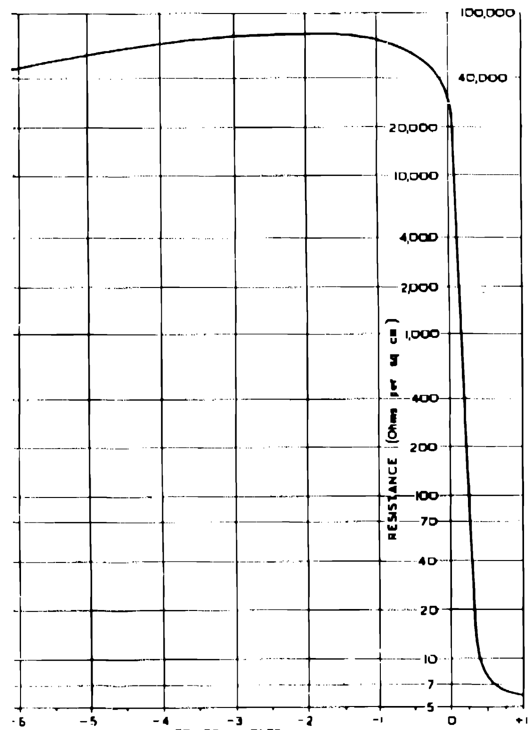


Fig. 51. Resistance/Voltage Characteristics of a Typical Copper-oxide Rectifier Element

of disc surface, but the overall capacitance of a rectifier is, of course, much reduced when there are a number of discs in series.

Fig. 52 shows a typical 12-element copper-oxide rectifier of the type used in telephony. It will be noted that, unlike rectifiers for power work, cooling fins between the elements are not provided. The

urrent to be carried by a rectifier is usually small nd intermittent, and the omission of the fins nables considerable economies to be made in the nounting space required. The rectifiers are made

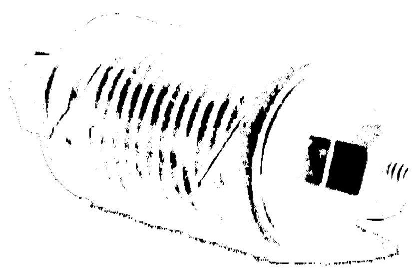


FIG. 52. A 12-ELEMENT COPPER-OXIDE RECTIFIER
Rectifier No. 1/12A.

in 6- and 12-element units with additional items comprising two or four such units on a common clamping screw. Each element is $\frac{3}{4}$ in. in diameter, and is rated to carry 50 mA in the forward direction. The limiting current in the reverse direction is

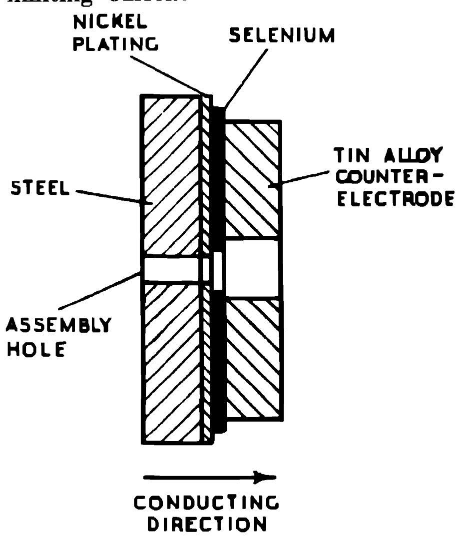


FIG. 53. DIAGRAMMATIC CROSS-SECTION OF A SELENIUM RECTIFIER ELEMENT

usually specified by limiting the back e.m.f. to 5 V per element. On simple rectifiers, one end washer is painted red, and when this end is wired to the positive terminal of a battery the rectifier is connected in the conducting direction.

Selenium Rectifiers. Selenium rectifiers are not much used in telephony except for heavy power work where they have a somewhat better performance than copper-oxide rectifiers at high temperatures. Fig. 53 shows the general make up of a selenium element. The base of the electrode is usually of nickel-plated steel. Black vitreous selenium is applied to the electrode, which is then raised to a temperature of some 200°C. The selenium is reduced by this heat treatment to a crystalline form known as *metallic selenium*. The counter-electrode consists of an alloy of tin which has a low melting point. The completed rectifiers are subjected to an electrical "forming" process which considerably increases the reverse resistance. Typical voltage current characteristics of a selenium rectifier are given in Fig. 54 which should be compared with the similar curves for the copper-oxide rectifier (Fig. 50). The main difference lies in the reverse current characteristic where a rise in temperature does not produce

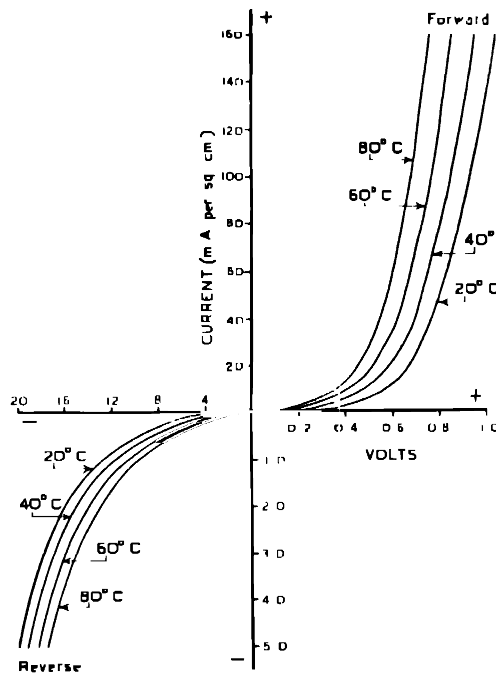


FIG. 54. VOLTAGE/CURRENT CHARACTERISTICS OF A SELENIUM RECTIFIER ELEMENT

a very great reduction in the reverse resistance, i.e. the power losses at high temperatures are less and the selenium rectifier can be safely worked at temperatures up to about 85°C. It will also be noted that the rapid increase of conductivity of the

selenium rectifier occurs at about 0·5 V positive compared with a figure of some 0·2 V for the copper-oxide rectifier. The selenium rectifier will withstand a reverse voltage of about 18 V per element as compared with a figure of 5 V for the copper-oxide rectifier.

Condensers. A condenser (or *capacitor*) in electrical engineering is a component primarily designed

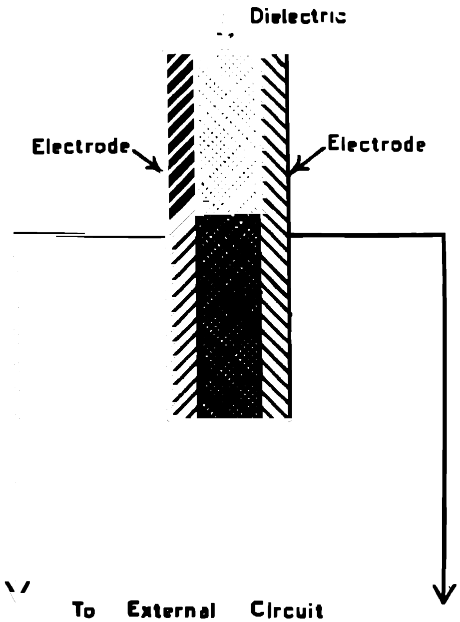


FIG. 55. PRINCIPLE OF A CONDENSER

for adding capacitance to a circuit. The principle of a condenser is illustrated in Fig. 55. It consists essentially of two metal plates or electrodes separated by an insulating material known as the *dielectric*. When a difference of potential is applied to the two electrodes there is a momentary electron flow from the lower potential electrode into the dielectric material. The quantity of electrons thus held in the dielectric space is dependent upon the nature of the material used for the dielectric. Some materials absorb a greater quantity of electricity than others for a given applied voltage. For purposes of comparison the absorption of air is considered as unity, and if a material is such that it will absorb, say, three three times the charge as air, then that material is said to have a *specific inductive capacity* or a *dielectric constant* of 3.

The capacitance of a condenser is the charge held per volt applied to the electrodes and a condenser is said to have a capacitance of 1 farad if a p.d. of 1 V between the electrodes results in a charge of 1 coulomb of electricity.

The capacitance of a simple condenser with parallel plates is given by:

$$\text{Capacitance} = \frac{kA}{9 \times 10^5 \times 4\pi t} \mu F$$

where k = the specific inductive capacity of the dielectric;
A = the surface area of one plate (sq cm);
t = the distance apart of the plates (cm).

A condenser offers an infinite resistance to direct currents but provides a transmission path for currents of an alternating nature. Possibly the greatest use of condensers in telephony is the segregation of d.c. signalling and a.c. speech paths. The reactance of a condenser to alternating currents varies inversely with the frequency of the current and with the size of the condenser, i.e.

$$\text{Reactance} = X = 1/\omega C$$

where ω = angular frequency (radn/sec);
C = capacitance (farads).

The reactance of a condenser must, of course, be considered in conjunction with the other electrical constants of the circuit (e.g. inductance); but generally speaking a condenser of large capacitance is required in a circuit which is to transmit low frequencies, whilst a smaller capacitance is sufficient for the higher frequencies. The following tabulation shows some examples of the reactance of typical condensers to 17 c/s signalling currents and to speech currents at the bottom, centre and top of the speech range.

Value of Condenser (μF)	Reactance (app. ohms) at 17 c/s	300 c/s	1000 c/s	3000 c/s
0 5	18 726	1062	318	106
1·0	9363	531	159	53
2 0	4682	265	79	26
4 0	2341	133	39	13

It will be noted that whilst an 0·5 μF condenser offers only reasonable reactance to speech currents in the upper range, such a condenser would not be suitable for circuits which are required to pass a 17 c/s signalling current. It is also apparent that the introduction of a condenser in a speech circuit always tends to produce frequency distortion due to the varying impedance offered to the different frequencies. Nevertheless, if the condenser impedance is small compared with that of the associated apparatus, the effect can be made negligible. This condition can usually be met in the design of telephone equipment.

There are numerous forms of condensers with various dielectric materials (paper, mica, ceramic, etc.), but it is possible in this volume to consider only the main types used in the signalling and switching circuits of telephony.

Condenser Construction. For many years most condensers used in telephony were of the Mansbridge type. This method of construction utilizes a form of "tinfoil paper" prepared by pasting tin, chemically reduced to a state of extremely fine subdivision, upon one side of a thin body paper. Two such papers are rolled up together so that the thin film of one spiral is separated from that of the other spiral by the paper which forms the dielectric. Often one or two strips of thin plain paper are interleaved between the spirals of "Mansbridge paper" to increase the dielectric strength and to improve the insulation resistance of the condenser.

The "Mansbridge" construction is little used now, as condensers made in this manner are more expensive and less efficient than condensers made by modern methods. The modern process of making a condenser unit consists in winding, in the form of a roll, two aluminium foils interleaved with a total of four or more impregnated papers (Fig. 56). In the P.O. standard 2μF condenser (M.C.102) there are two layers of paper between the foils, each paper being 0·009 mm thick, whilst each foil is 0·006 mm thick and has a surface area (one side)

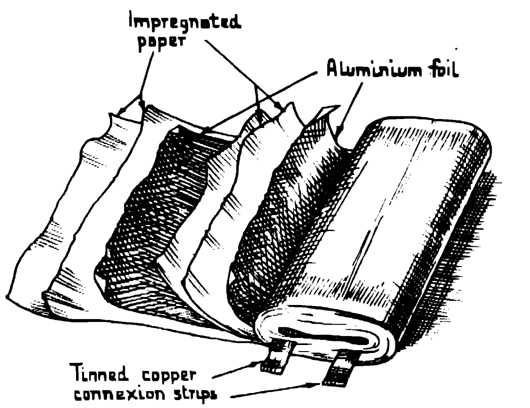


FIG. 56. THE MAKE-UP OF A PAPER DIELECTRIC CONDENSER

of 4 to 5 sq ft. Tinned copper strips are inserted in the roll to provide a connexion between the foils and the tags of the condenser. The rolled unit is then pressed flat to give an increased capacitance and whilst still clamped is impregnated with petroleum jelly or chlorinated naphthalene. Paraffin wax impregnation which was formerly used exclusively has now been largely superseded.

The impregnation process used by one manufacturer is to desiccate at 120° C for twelve hours by circulating dry air over the clamped units, then quickly to transfer the work to the pans (maintained at 120° C) in which the impregnation process will be carried out. Vacuum is applied for a period of twelve hours, when the wax or jelly is allowed to

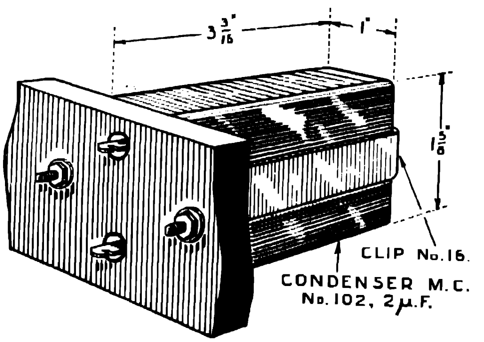


FIG. 57. A 2-μF CONDENSER AND MOUNTING CLIP

enter the pans. The vacuum is maintained for six hours more and then slowly released to allow the impregnating tanks to regain atmospheric pressure. After impregnation, the condensers are quickly transferred to a bath of sealing compound and, after cooling, the units are tested for insulation resistance, dielectric strength, and capacitance. Great care must be exercised throughout the manufacture when chlorinated naphthalene is used to ensure that unfinished condensers are not left exposed to the atmosphere, as the wax is hygroscopic.

The standard condensers used for telephone purposes are made up in metal cases designed for attachment to the mounting plate by means of a U-shaped clip (Fig. 57). The height (3$\frac{3}{16}$ in.) and width (1$\frac{5}{8}$ in.) of the units are constant for all values of capacitance, the thickness varying with the value of the condenser. The main sizes are:

No. 101 — 1μF — $\frac{1}{2}$ in. thick;
No. 102 — 2μF — 1 in. thick;
No. 103 — 4μF — 2 in. thick.

It is interesting to note that, since the standardization of these condenser sizes, various improvements have been made in condenser technique so that it would be possible to accommodate at least twice the capacity in the standard cases.

Electrical Characteristics. The standard condensers used in telephony are designed to withstand a working voltage of 200 V d.c., and must not break down with a test voltage of 300 V d.c.

A high value of insulation resistance is required, and a minimum value of 1000 "megohm-microfarads" (*not* megohms per microfarad) is specified. The term "megohm-microfarads" (sometimes called the *KR value*) is given to the product of the insulation resistance of the condenser under test in megohms, and the capacitance of that condenser in

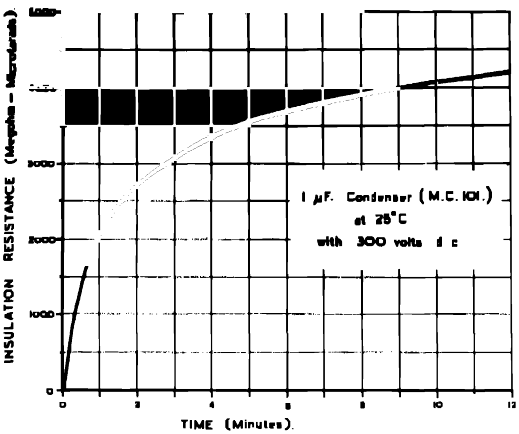


FIG. 58. SHOWING THE RISE OF APPARENT INSULATION RESISTANCE OF A CONDENSER DURING CHARGING

microfarads. (Some prefer to use the term "ohm-farads" in place of "megohm-microfarads," but it will be seen that the terms are synonymous.) Thus, a 2 μF condenser would require to have a minimum insulation resistance of at least 500 MΩ to meet the minimum requirement of 1000 megohm-microfarads. The charging time of a condenser is appreciable (Fig. 58), and during this period the apparent insulation resistance increases—particularly in the first two or three minutes. It is therefore necessary to specify the time after commencement of electrification at which the insulation resistance must be measured. This time is usually one minute after the application of the testing voltage.

Another interesting characteristic is the very rapid change of insulation resistance with change of temperature. Fig. 59 shows how the insulation resistance decreases as the temperature is raised from 0° C to 70° C. A 10° rise of temperature (from 15° C to 25° C) results in a 50 per cent reduction in the value of the insulation resistance. It is therefore highly important that the resistance should be measured at a specified temperature (usually 60° F or 15·6° C).

The "capacitance tolerance" of a telephone condenser, i.e. the percentage by which the capacitance is permitted to depart from the nominal value, is usually ± 10 per cent. There is little change in capacitance during the life of a condenser at operating temperatures up to 50° C. The capacitance may be measured either by comparing the discharge through a ballistic galvanometer with that of a standard condenser, or by an a.c. bridge method.

Electrolytic Condensers. The smoothing condensers required for float type power plants must be of large capacitance to absorb the mains or machine ripple voltage. Electrolytic condensers have been extensively used for this purpose in recent years owing to their lower initial cost and smaller dimensions for a given capacitance. The electrolytic condenser differs from the ordinary condenser in that the dielectric takes the form of a very thin insulating film on the surface of one electrode, and the second electrode is separated

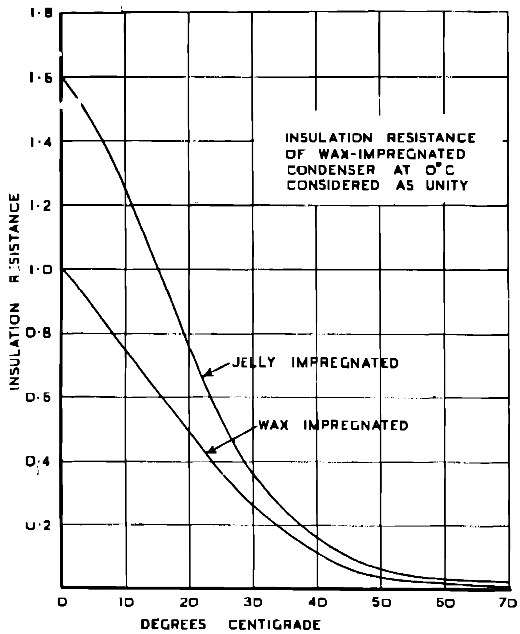


FIG. 59. VARIATION OF INSULATION RESISTANCE WITH CHANGE OF TEMPERATURE

from the dielectric by a conducting electrolyte (Fig. 60). The presence of the electrolyte ensures that the second electrode is in intimate electrical contact with the whole of the dielectric film, but at the same time prevents short circuits between the electrodes which might otherwise occur due to microscopic imperfections in the dielectric film. The electrolyte also increases the apparent specific inductive capacity of the dielectric film. The most important function of the electrolyte is, however,

the maintenance of the dielectric film by electrolytic action during the working of the condenser. Hence it is apparent that electrolytic condensers should always be provided with a polarizing d.c. voltage so connected that the electrode on which the dielectric film is formed is positive, i.e. it must be the anode of the electrolytic cell. According to one theory, the very high capacitance obtainable from electrolytic condensers is due to partial absorption of the electrolyte into the dielectric film, thus leaving an extremely thin insulating layer between the two conducting sides of the condenser. Any breakdown of the dielectric film results in the passage of d.c. which generates gas at the anode due to electrolytic action and quickly seals the break with minute gas bubbles.

The electrodes are usually constructed of aluminium and the electrolyte may be a solution of any weak alkaline salt which has good film forming properties, e.g. ammonium tetraborate. During the forming process, oxygen is liberated at the anode which reacts with the aluminium to form an insulating dielectric film of aluminium oxide (Al_2O_3). In the early "wet type" electrolytic condenser, the electrolyte was an aqueous solution. Later, glycerine, gums, and various colloidal thickening agents were introduced to produce a more viscous electrolyte, and such condensers are known as the *semi-dry* type. The process has been still further developed in the modern *dry* type of condenser in which the film-forming chemical is mixed with other ingredients to produce an electrolyte which is quite hard and dry at normal working temperatures. In such electrolytes alcohol is commonly employed as the ionizing agent instead of the water of earlier types.

The construction of the dry electrolytic condenser is very similar to that of the ordinary paper dielectric condenser. The electrodes are of aluminium foil wound together with a cotton gauze separator which has been previously impregnated with the electrolyte. The foil is often crimped or etched to increase the surface area and hence the capacity.

The electrical performance of an electrolytic condenser is not so good as a well-designed condenser of the ordinary type. For smoothing work, however, the lower efficiency is not of great consequence. The leakage current of an electrolytic condenser may be as high as 0·5 mA/μF when the voltage is first applied, but this leakage falls rapidly due to the film forming process and in two or three minutes stabilizes at a value in the order of 0·01 mA/μF. It is important that the ripple voltage should be small compared with the d.c. polarizing voltage to avoid destruction of the film consequent upon the reversal of voltage on the condenser.

The power factor of an electrolytic condenser is also much higher than that of an ordinary condenser, especially at high frequencies, and care must be taken to prevent overheating. At 1000 c/s, for example, the power factor of a good paper condenser is in the order of 0·005, compared with a figure of, say, 0·25 for an electrolytic condenser.

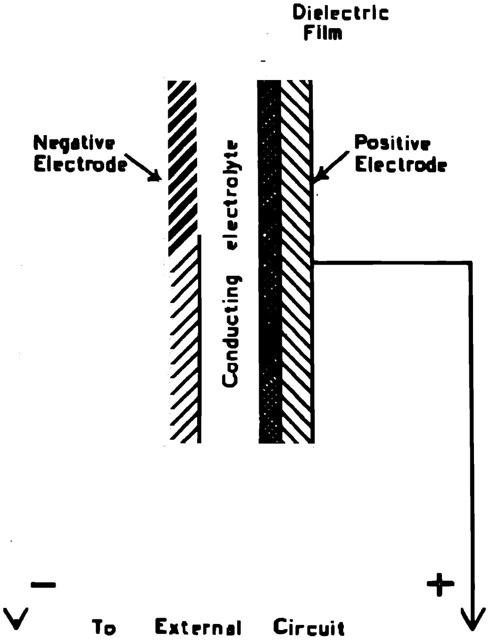
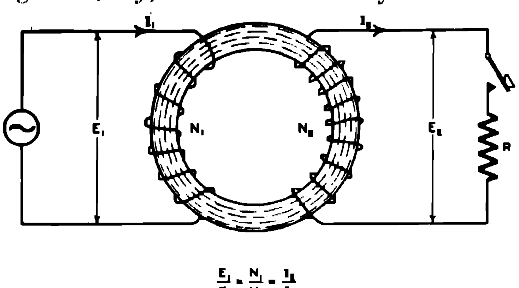


FIG. 60. PRINCIPLE OF THE ELECTROLYTIC CONDENSER



$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

FIG. 61. PRINCIPLE OF THE TRANSFORMER

The Transformer. The transformer is a static device which enables two (or more) alternating current circuits to be coupled together electromagnetically. By suitably adjusting the coupling arrangements an alternating voltage in one circuit can be "transformed" to any desired value in the

second circuit. The transformer is dependent for its operation upon two important electromagnetic laws:

(*a*) When a current passes through a conductor a magnetic field is produced round the conductor, the intensity of the field at any instant being directly proportional to the value of the current.

(*b*) If a conductor is placed in a magnetic field of varying intensity an e.m.f. is generated in the conductor, the value of the e.m.f. being directly proportional to the rate of change of magnetic field strength.

The transformer consists, in principle, of two windings—usually known as the *primary* and *secondary*—wound on a common iron core (Fig. 61). If an alternating current (I_1), is passed through the primary winding, it produces a magnetic flux in the core which varies instant by instant in accordance with the value of the current. In an ideal transformer this flux links with every turn of both windings and induces in each turn the same voltage. If the rate of change of flux at some particular instant produces e volts per turn, then the total voltage induced in the primary is:

$e \times N_1 = E_1$ (where N_1 = no. of turns on primary);

from which $e = E_1/N_1$ . . . . (1)

Similarly, the total voltage induced in the secondary is:

$e \times N_2 = E_2$ (where N_2 = no. of turns on secondary);

and $e = E_2/N_2$ . . . . (2)

Equating (1) and (2),

$E_1/N_1 = E_2/N_2$ or $E_1/E_2 = N_1/N_2$ . . . . (3)

Thus, in an ideal transformer, the ratio of the primary and secondary voltages is equal to the ratio of the primary and secondary turns. This relationship is not quite true in a practical transformer for reasons which will be seen later, but it is sufficiently accurate for most purposes. The error is in any case not usually greater than 1 per cent.

It is apparent that the e.m.f. induced in the primary winding must always (in the ideal transformer) be equal and opposite to the applied voltage. If the flux linking with the primary winding is for any reason reduced, then the current in the primary automatically increases until the e.m.f. produced in the winding by induction is equal and opposite to the applied e.m.f. If, now, the secondary circuit of the transformer is closed, the resultant current in the secondary winding produces a magnetic field which by Lenz's Law opposes the original flux in the core. This reduction of flux, in turn, produces an increase of primary current. The primary current is therefore dependent upon the value of the current in the secondary. For a transformer with no inherent losses, the power input to the primary side must equal the power output from the secondary, i.e.:

$$I_1E_1 = I_2E_2$$

or $E_1/E_2 = I_2/I_1$

But $E_1/E_2 = N_1/N_2$ (equation 3);

$\therefore I_2/I_1 = N_1/N_2$ . . . . . . (4)

Thus, for the ideal transformer under consideration, the ratio of the primary and secondary currents is equal to the reverse of the turns ratio.

To summarize, the transformer provides a ready and efficient means of converting a.c. power at one pressure (e.m.f.) to a similar power at any other desired pressure. By its use, a heavy alternating current of low voltage can be transformed to a lighter current at a higher voltage, and vice versa.

Losses in Transformers. In power engineering, a transformer is usually designed to operate at one particular frequency (e.g. 50 c/s) and the designer is primarily concerned with the voltage output under various conditions of load. Transformers for telephone use, on the other hand, are required to perform efficiently over a wide range of speech frequencies, and in some cases are also required to transmit a.c. signalling currents of very low frequency.

It is not possible to produce a transformer which meets the ideal conditions already considered. It is desirable, however, that the losses introduced should be small and should be substantially uniform over the speech frequency range. If this latter condition is not obtained then frequency distortion is introduced. It is even more important that the losses should be directly proportional to the power transmitted in order to avoid amplitude distortion.

The losses in a transformer may be studied by the preparation of circuits which are electrically equivalent to the transformer. Fig. 62 shows a source of alternating current with an internal impedance Z_1 coupled by means of a transformer to a second circuit Z_2. For simplicity the transformer is assumed to have equal turns on the primary and secondary windings. Under ideal conditions, the voltage across the primary winding is equal to and in phase with the voltage across the secondary winding. Also, any change of current in one circuit must be accompanied by an exactly similar change in the other circuit. For purposes of analysis, therefore, the ideal transformer can be omitted and the two sides connected together as shown at (*b*).

In an actual transformer there are five main sources of power loss:

(a) the loss due to the magnetizing current;

(b) hysteresis losses in the iron core;

(c) eddy current losses in the iron core;

(d) losses due to the incomplete linking of the flux with each turn of both windings; and

(e) the ohmic resistance loss of the windings.

In addition to the above, the capacitance between windings and the inter-turn capacitance should theoretically be considered. The effects of these capacitances are negligible at speech frequencies, and they are not usually considered except in certain transformers with a very large number of secondary turns. In such cases the internal capacitance of the secondary tends to produce a resonant condition at the higher frequencies.

Shunt Losses. It is convenient to consider transformer losses under the headings of "shunt losses" and "series losses." The first source of shunt loss is due to the magnetizing current, i.e. the current which flows in the primary winding when the secondary circuit is open. This current is determined purely by the inductance of the primary winding and, if no other losses are present, the magnetizing current lags 90° behind the voltage at the transformer terminals. It is important to realize, however, that, even under these conditions, the magnetizing current introduces a power loss by virtue of its passage through the impedance of the external primary circuit (Z_1). The magnetizing current loss can, then, be represented by a pure inductance L_1 connected across the circuit (Fig. 62 (c)). The reactance of this shunt path is given by ωLI where $\omega = 2\pi f$. It is apparent, that the reactance is small at low frequencies and high for the higher frequencies. The shunt loss is thus large at low frequencies and negligible at the higher frequencies of the speech range. It follows that if a transformer is to pass low frequencies without serious loss the inductance of the primary winding must be high.

The hysteresis loss is proportional to the area of the hysteresis loop, which in turn is determined by the quality of the iron used for the core. The hysteresis loss is therefore dependent upon the maximum value of flux-density (which controls the height of the hysteresis loop) and upon the frequency (which determines the number of loops per second). The eddy current loss in the core is due to the e.m.f. induced in the core itself by the varying field. This loss increases as the square of the frequency, for if the frequency is doubled, the voltage induced in the core is doubled. The power loss is given by the square of the voltage (E^2/R) and is therefore four times as great.

The hysteresis and eddy current losses can be represented on the equivalent circuit diagram by a high resistance R_1 in parallel with L_1. At the first glance it would appear that the iron losses increase approximately as the square of the frequency and that it is incorrect to show the loss as a constant

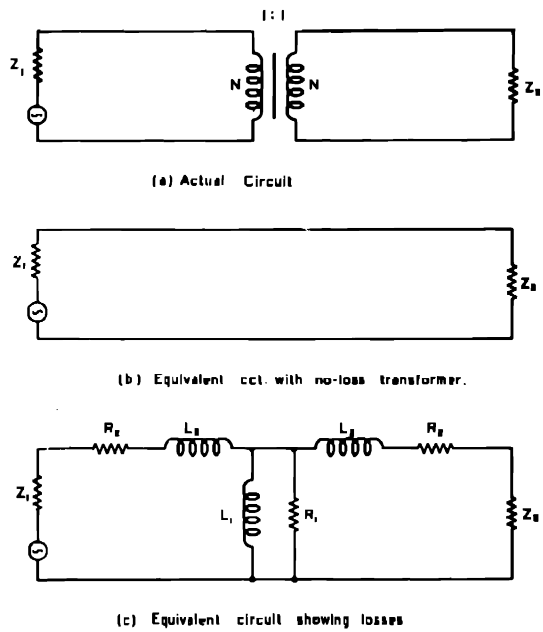


FIG. 62. EQUIVALENT CIRCUIT OF A TRANSFORMER

resistance. It can be shown mathematically, however, that as the frequency increases, the flux-density in the core decreases, thereby counteracting to a large extent the rise in loss with increased frequency. For frequencies up to about 2000 c/s the value of R_1 is substantially constant and therefore introduces a uniform power loss throughout the speech-frequency range.

Series Losses. It has so far been assumed that the magnetic field produced by each turn links with every other turn of the transformer windings. In practice there is always a flux leakage around the turns and between the windings which prevents a full linkage of flux with every turn (Fig. 63). The leakage flux is determined partly by the permeability of the core and partly by the physical disposition of the windings. In a good telephone transformer the leakage flux is generally less than 1 per cent. Flux leakage may be shown on the equivalent circuit as "free" inductances L_2 in series with the primary and secondary circuits (Fig.

62 (*c*)). The reactance of the leakage inductances increases with rise of frequency ($X = \omega L$), but since they are in *series* with the main circuit the loss introduced rises as the frequency is increased. This produces a heavy loss at the higher

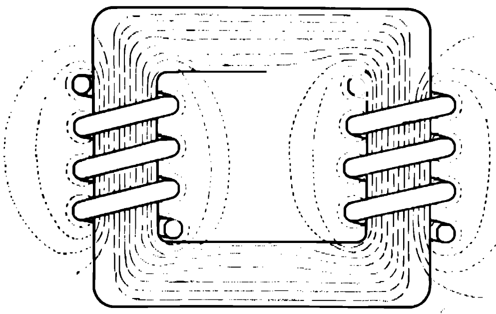


Fig. 63. Flux Leakage in a Transformer

frequencies and a negligible loss at the lower speech frequencies.

The final loss is due to the ohmic resistance of the windings themselves. This loss can be illustrated simply by the introduction of non-inductive resistances R_2 in series with the circuit. The complete equivalent circuit showing the various losses is illustrated in Fig. 62 (*c*), whilst a typical power loss curve for an audio-frequency transformer is shown in Fig. 64. The loss at 30 c/s is in the order of 5 db, but this loss decreases rapidly up to about 300 c/s. From 300 c/s to 3000 c/s the loss is substantially uniform at about 1 db, but beyond this the loss again rises to reach 3 db at 20 000 c/s. It is apparent from the previous considerations that:

(*a*) a better performance at low frequencies can be obtained by increasing the inductance of the primary winding;

(*b*) the loss in the middle frequency spectrum can be reduced by decreasing the iron and copper losses; and

(*c*) the high-frequency performance can be improved by a reduction in the leakage flux.

The transmission loss of a transformer is of course dependent upon the value of the impedance to which it is connected. If the terminal impedances are very low then the shunt loss is low and the series loss is high. Conversely if the transformer is in a circuit of very high impedance the shunt loss is large and the series loss is small. Transformers are therefore designed to work with specific terminal impedances.

Transformer Construction. The core material of a speech transformer should have:

(*a*) a high permeability to obtain a high primary inductance;

(*b*) a high specific resistance to reduce the value of eddy currents; and

(*c*) a low hysteresis loss.

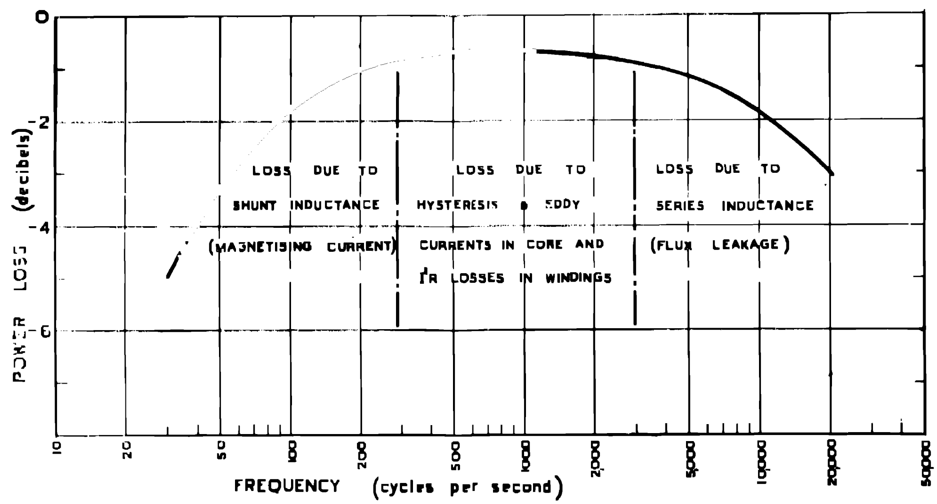


Fig. 64. Transmission Loss Introduced by a Typical Transformer at Various Frequencies

Silicon-iron alloys were extensively used in the past but have now been largely superseded by alloys of nickel and iron, sometimes with a small percentage of copper and manganese. Very high permeabilities are obtainable with certain nickel-iron alloys, but saturation occurs at very low values of flux-density. Nevertheless telephone trans-

formers are required to handle only very small powers and the early saturation is not a serious disability. The following tabulation shows some magnetic characteristics of typical core materials.

	Mumetal	Radio-metal	Silicon Iron	Armco Iron
Specific Resistance ($\mu\Omega$ per cm^3)	42	55	60	10
Initial permeability	20 000	2000	300	250
Maximum permeability	80 000	12 000	7000	5000
Magnetizing force (H) for maximum permeability	0·03	0·4	0·9	1·2
Max. flux-density	9000	15 000	16 000	20 000
Hysteresis loss (ergs per cm^3 per cycle)	50	350	550	1000

In order to reduce eddy current losses, all transformer cores are made up of thin laminations coated with an insulating film. The division of the core in this manner reduces the value of the e.m.f. induced in each lamination and also increases the length (and hence the resistance) of the eddy current paths. In earlier transformers, iron wires were used instead of flat laminations to obtain the same results. Transformer cores are of three main types, the *ring type* as illustrated in Fig. 61, the *core type* as shown in Fig. 63, and the *shell type* (Fig. 65). The advantage of the ring type core is that it can be made jointless and by evenly distributing the windings round the core, very small values of leakage flux can be obtained. The disadvantage of the ring core is the difficulty of winding and of completely filling the winding space. The core type is usually made up of short and long limbed U-shaped stampings which are interleaved to provide a good magnetic joint. By placing the windings on opposite limbs, the design is useful when a high breakdown voltage is required. Alternatively, by dividing the windings equally on both limbs the transformer can be made immune from the effects of external magnetic fields. The shell type of core (Fig. 65) is by far the most common. All the windings are concentrated on one simple bobbin and the transformer is assembled by interleaving U- and T-shaped stampings so that the magnetic joints of each layer "break" with those of the adjacent layers.

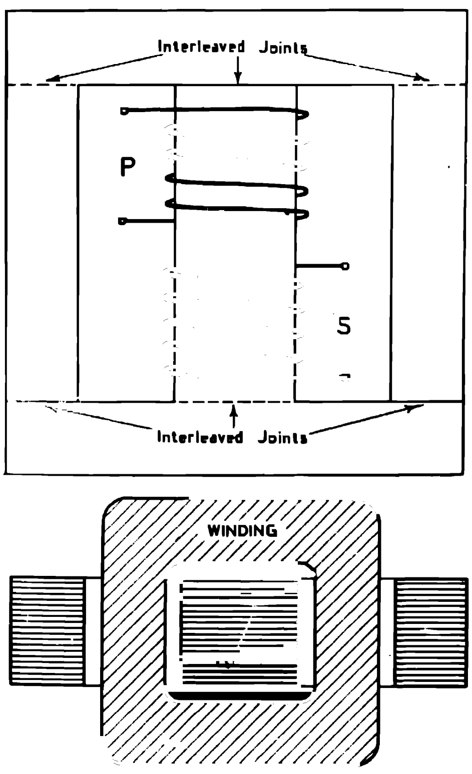


FIG. 65. THE CONSTRUCTION OF A TRANSFORMER WITH "SHELL TYPE" CORE

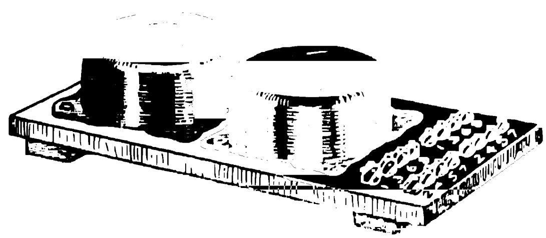


FIG. 66. TWO REPEATING COILS ON A COMMON BASEBOARD

Transformers Carrying Direct Current. Very often, a speech transformer is required to carry d.c. signalling or other currents. Any such direct current introduces a polarizing field in the core with the consequent reduction in a.c. permeability. The reduction of permeability, in turn, decreases the open circuit inductance of the windings with a corresponding increase of loss at low frequencies. To minimize this effect an air gap is inserted in the

core and has the effect of decreasing the d.c. magnetizing field. If the air gap is made too large, the reluctance of the magnetic circuit to a.c. flux is increased and there is therefore an optimum value for the best results.

It should be noted that when an air gap is provided it should be located inside the windings. If the air gap is placed at some point away from the winding, there is a considerable amount of flux leakage across the centre air space due to the high reluctance of the regular flux path which includes the air gap. If, on the other hand, the winding is arranged over the air gap, the leakage flux is small due to the low reluctance of the alternative iron path.

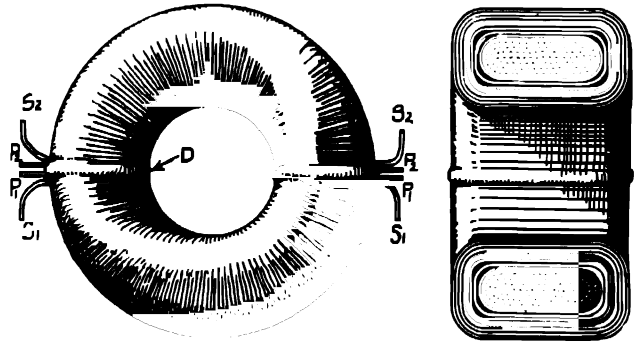


Fig. 67. Repeating Coil with Iron Case Removed

Repeating Coils. The speech transformers designed in the early days of telephony were known as *repeating coils* due to their function of "repeating" speech currents from one circuit to another. Although the design is now obsolete, a considerable number of repeating coils are still in use, particularly at manual exchanges. Fig. 66 shows a typical unit of two repeating coils mounted on a wooden base, whilst Fig. 67 shows side and cross-section views of a coil without the outer iron case. The core is of toroidal form made up of a large number of iron wires to minimize eddy current losses. The windings are segregated on the two sides of the core with fibre spacers (*D*) to isolate the two series of windings. When windings with identical electrical characteristics are required (balanced windings) it is usual to wind with a twisted pair—one conductor of the pair forming one

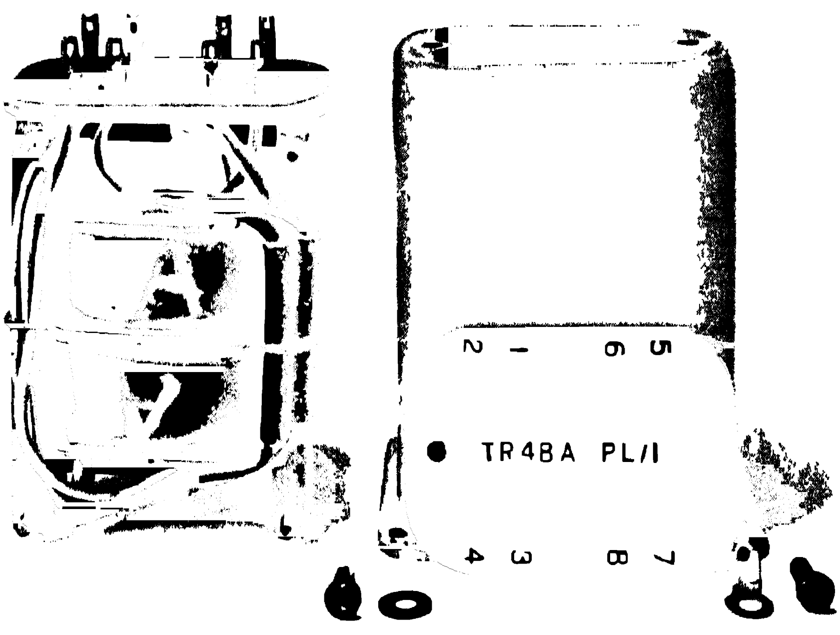


Fig. 68. A Modern Type of Telephone Transformer
Transformer No 48

winding and the second conductor the other winding. After winding, the coil is sealed with resin or wax into the iron case which prevents mechanical damage and also provides an electromagnetic shield. Repeating coils are more costly to manufacture and are electrically less efficient than transformers of modern design. Moreover, the mounting space required is much greater.

Modern Transformers. Fig. 68 shows a typical speech transformer of modern design (P.O. Transformer No. 48). The transformer is much more compact than the early repeating coils and is suitable for mounting along with other apparatus on a relay mounting plate. The core is the of "shell" type and is built up of nickel-iron laminations. The core section is almost $\frac{1}{2}$ in. × $\frac{1}{2}$ in. and the magnetic length is about $5\frac{1}{2}$ in. with no air gap. The bobbin, is divided into two portions and the windings are arranged symmetrically on each side of the bobbin. Double wire or a twisted pair is invariably used when two windings are to be accurately balanced. This particular transformer has a primary inductance in the order of 1 H with no d.c. present in the windings. It is specified to have a transmission loss, at 800 c/s, not greater than 0·75 db with 40 mA in the windings. Moreover, the loss between 300 and 5000 c/s shall not be greater than ± 0·5 db from the value at 800 c/s with no d.c. in the windings. The insulation between separate windings must withstand a d.c. test voltage of 500. The transformer No. 48 is manufactured in a number of ratios to meet the various needs of telephone circuits.

Induction Coils. The induction coil (Fig. 69) is a small and inexpensive transformer designed primarily for use in telephone instruments. It has an

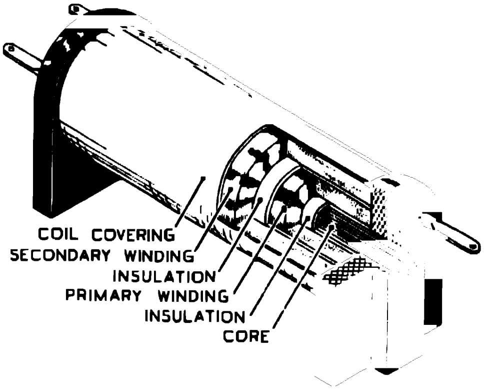


Fig. 69. Partial Section of an Induction Coil

open magnetic circuit with a straight core of soft iron wires which are left black from the annealing process. The windings are placed one above the other on a cylindrical bobbin with moulded bakelite cheeks, the latter accommodating the connexion tags. The coils are usually wound with enamelled, single silk-covered wire with a layer of empire cloth between windings. Modern induction

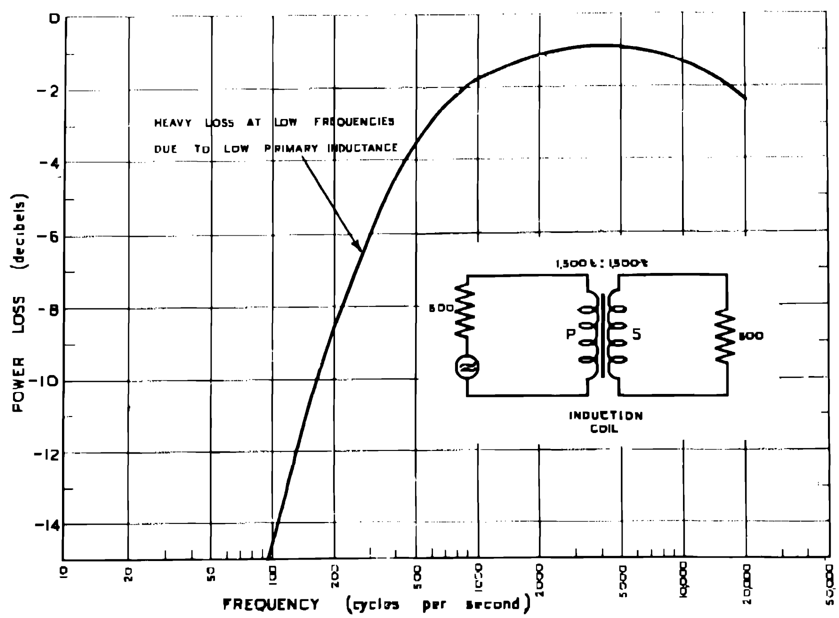


Fig. 70. Typical Transmission Loss/Frequency Characteristics of an Induction Coil

coils may have as many as three or four windings and may also include certain non-inductive resistance coils which are required in the telephone circuit.

The performance of an induction coil is somewhat different from that of a good speech trans-

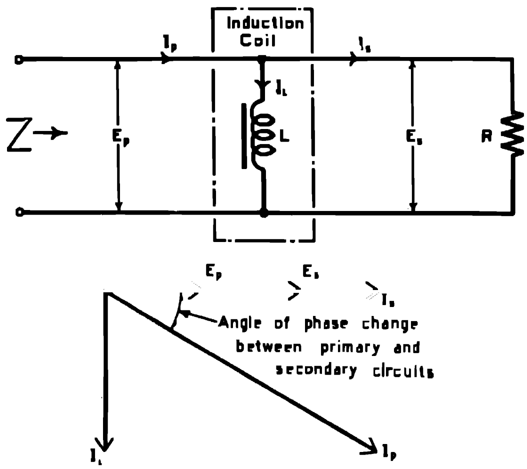


FIG. 71. SHOWING HOW LOW PRIMARY INDUCTANCE INTRODUCES PHASE CHANGE BETWEEN PRIMARY AND SECONDARY CIRCUITS

former of the more usual pattern. The open core construction gives a very low primary inductance (about 0·1 H) and this introduces a heavy shunt loss particularly at low frequencies. Fig. 70 shows the power loss introduced by a typical induction coil at various frequencies and should be compared with the similar curve (Fig. 64) for a transformer of the more usual type. Although the curve is substantially flat over the range 2000 c/s to 6000c/s, the power loss increases rapidly below about 1000 c/s and is in the order of 6 db at 300 c/s. An induction coil is therefore not suitable for the transmission of low frequencies and when placed in a speech circuit causes frequency distortion due to the abnormal attenuation of the lower frequencies.

The low primary inductance has a further important effect. When an induction coil is connected in a transmission circuit it materially alters the angle of the circuit impedance. This is apparent from Fig. 71 which gives an elementary vector diagram without the complications introduced by the various induction coil losses. If the induction coil is omitted from this circuit, the impedance Z measured from one end will be non-reactive and equal in magnitude to R. The introduction of the induction coil, however, places an

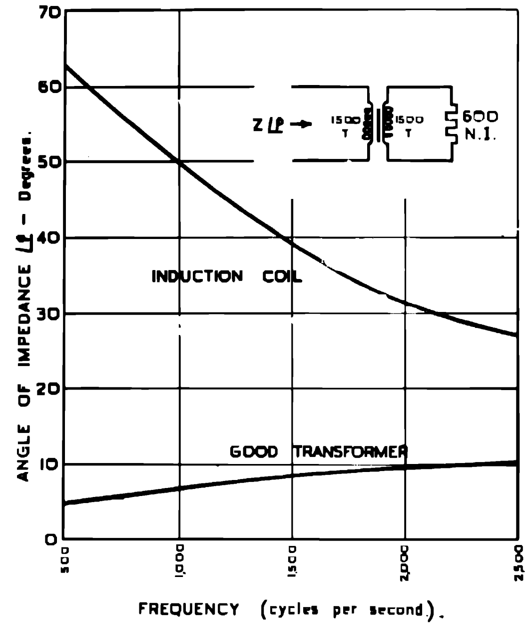


FIG. 72. COMPARISON OF THE PHASE CHANGE INTRODUCED BY AN INDUCTION COIL AND A GOOD SPEECH TRANSFORMER

inductance L in parallel with R and hence the measured impedance Z will have a lagging angle which is greatest at low frequencies when the reactance of L is low. There is therefore an appreciable phase difference between the current in the primary circuit (I_p) and the voltage (E_s) and current (I_s) in the secondary circuit. Fig. 72 shows the results of tests on a typical induction coil. With a non-inductive impedance of 600 Ω across one-winding the impedance $Z\angle\phi$ is measured at the terminals of the second winding. At an average speech frequency of 1000 c/s, the angle of the impedance is about 50° lagging but decreases as the frequency is raised.

EXERCISES IV

1. Describe a common type of resistor used in the signalling and switching circuits of telephony.

2. Describe, briefly, the construction of a condenser as used in telephony, and state the factors that determine the capacitance of the condenser. . . . (*C. & G. Telephony, Grade I*, 1944.)

3. A circuit contains an earthed 40 V battery, a 50 Ω resistor and a 1000 Ω relay all in series in the order given. The resistor will dissipate up to 9 W without risk of fire. Is the circuit safe? If not, how would you introduce additional resistors of the same type and value to avoid the fire risk?

4. Describe the method of manufacture and the construction of a copper-oxide rectifier suitable for use in telephone signalling circuits. Show by means of a curve how the current through such a rectifier is dependent upon the voltage across its terminals.

5. Describe the construction and colour code system of carbon type resistors.

6. Give a brief summary of the electrical characteristics of a paper dielectric condenser of the telephone type. In what respects do the characteristics of an electrolytic condenser differ from those of an ordinary condenser?

7. Describe the principle and main features of construction of a transformer for stepping up small alternating voltages produced by speech currents. What are the required characteristics of the material forming the core if the transformer is to be compact and efficient? (*C. & G. Technical Electricity, Grade II*, 1944.)

8. A complex speech wave of 1 V peak is applied to a telephone receiver. Describe with the aid of sketches how the current in the receiver is modified when a copper-oxide rectifier element is connected in parallel with the receiver.

9. Describe the construction of an induction coil suitable for a local battery telephone. Give reasons for the formation of the core and windings.

An alternating voltage is applied to the primary winding of an induction coil (*a*) with the secondary coil terminals left disconnected, (*b*) with the secondary coil circuit completed by means of a non-inductive resistance of low value. Explain why the currents in the primary winding are of different value in the two cases. (*C. & G. Telephony, Grade I*, 1941.)

10. Discuss the factors which lead to imperfect transmission of an electric current through a transformer and give the equivalent network for a transformer having unity ratio. (*C. & G. Transmission and Lines, Grade II*, 1940.)

11. A perfect transformer has a primary/secondary turn ratio of 1/5 and the secondary winding is closed by a non-reactive resistance which absorbs 10 W when the primary current is 2 A. What is the resistance of the secondary circuit?

CHAPTER V

THE TRANSMISSION ELEMENTS OF TELEPHONE CIRCUITS

A SIMPLE telephone circuit to provide conversation in one direction only is illustrated in Fig. 73. In this circuit a carbon transmitter, battery, and receiver are all in series, the direct current for the energization of the transmitter being determined by the total ohmic resistance of the circuit. Under quiescent conditions the direct current through the transmitter produces a steady p.d. across it but, when a sound wave impinges on the diaphragm,

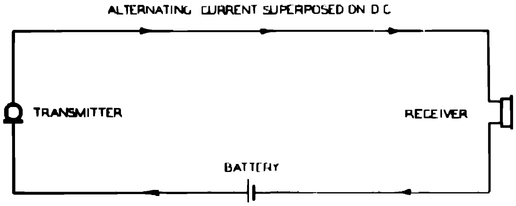


FIG. 73. ELEMENTARY UNIDIRECTIONAL TELEPHONE CIRCUIT

the resistance of the transmitter alternates above and below the steady value. The resultant fluctuating p.d. at the transmitter terminals may be considered as a steady direct voltage upon which is super-imposed an alternating voltage of speech frequency. The steady direct voltage, being constant, does not affect the receiver. Hence, the transmitter, from a speech point of view, is essentially a generator of voice frequency alternating voltages. It should be noted that whilst the intensity of the sound wave determines the change of transmitter resistance, the amplitude of the alternating voltage at the transmitter terminals is dependent upon both the change in resistance and the direct current through the transmitter. For example, a change of resistance of 5 Ω at some particular instant produces a change of voltage ($I \times r$) of 250 mV at the terminals when the direct current through the transmitter is 50 mA, but when the current is 100 mA the change of voltage for the same change of resistance is 500 mV. Thus, the carbon transmitter is an a.c. generator, the output of which is determined by the value of the energizing direct current and the sound pressures applied to it.

In Fig. 73 the alternating voltage at the transmitter produces a corresponding alternating current round the loop via the receiver and battery. The alternating current, super-imposed on the steady direct current in the receiver, produces corresponding variations of the pull on the diaphragm, thereby reproducing in a more or less faithful form the original sound waves applied to the transmitter.

This elementary circuit has certain obvious disabilities. Firstly, the transmitter energizing current (and hence its a.c. output) is dependent on the total resistance of the circuit. As the distance between the sending and receiving points is increased, the resistance of the connecting line also increases. Thus, to maintain the same transmitter output, the e.m.f. of the battery must be increased in order to retain the transmitter energizing current at the same level. Apart from the impracticability of adjusting the battery voltage for each individual line, a limit is soon reached when it becomes uneconomical to provide the required number of cells. The solution (apart from a method to be described later of providing a high voltage battery at some central point to serve a number of telephones) lies in so designing the telephone circuit that the transmitter and battery form a local circuit, the resistance of which is independent of the line. Telephone systems in which each transmitter is energized by an individual battery connected in the local transmitter circuit are often referred to as *local battery systems*, to distinguish from the alternative method of energizing a number of transmitters from a common battery centrally located—*central battery systems*.

In the circuit of Fig. 73 the direct current flows through the receiver. This direct current could, as in some of the earlier systems of telephony, be utilized to polarize the receiver in lieu of a permanent magnet, but as permanent magnet receivers are now universal, the presence of a direct current is of no value and is, in fact, deleterious. If such a direct current is present, great care must be taken to connect the receiver the correct way to avoid demagnetization of the receiver and degradation of transmission. Fig. 74 shows how the efficiency of a receiver is reduced by the presence of a demagnetizing current. If a typical transmitter current of, say, 80 mA, passes through the receiver in the demagnetizing direction the receiving efficiency is reduced by about 6 db. For higher values of current the effect is even more marked. Even if the receiver is correctly connected, the presence of a direct current produces a static pull on the diaphragm which varies with the value of the current and so makes the design of the receiver difficult and its performance somewhat variable.

The provision of a local circuit for the transmitter and battery, together with the prevention of a direct current in the receiver, are attained in the circuit of Fig. 75. In this circuit an impedance coil or choke is introduced to prevent the shunting of the alternating current by the battery, and a condenser is placed in series with the line, so preventing the flow of direct current, whilst at the

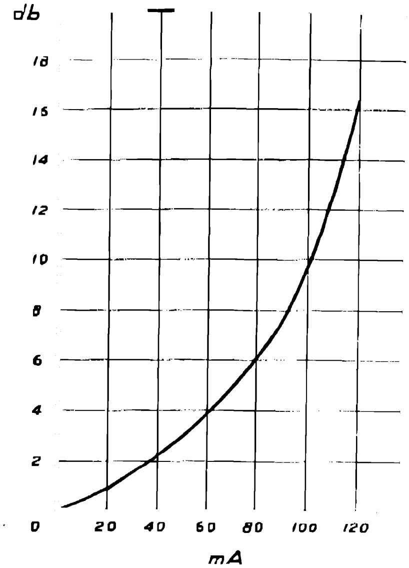


FIG. 74. EFFECT ON RECEIVER EFFICIENCY OF A DEMAGNETIZING CURRENT IN THE WINDINGS

same time readily passing alternating currents of voice frequency.

Impedance Matching. The circuit as now developed has still one fundamental disability. It can readily be shown that in a direct current circuit consisting of a battery and an external resistance in series, the maximum power is delivered to the external load when the external resistance is equal to the internal resistance of the battery. In a similar manner, if any source of alternating e.m.f. is connected to an external impedance, the maximum power transfer occurs when the external impedance is equal to the internal impedance of the generator. This very important principle, which has innumerable applications in telephony, is illustrated in Fig. 76. At (*a*) a battery of four volts e.m.f. and of 100 Ω internal resistance is connected to a variable external load *R*. The curve below shows the power absorbed by the external load with different values of *R* from 0 to 480 Ω. The power absorbed by *R* increases up to a maximum of 40 mW and then gradually falls away to become 0 when the value of *R* is infinitely great. The maximum value occurs when the external resistance equals the internal resistance of the battery, i.e. 100 Ω. The same conditions apply if the battery is now replaced by an a.c. generator having an internal impedance of 100 Ω and with a similar

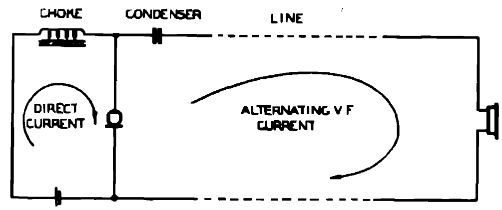


FIG. 75. USE OF A CHOKE AND CONDENSER TO PREVENT THE PASSAGE OF DIRECT CURRENT THROUGH THE RECEIVER AND TO EXCLUDE THE LINE FROM THE TRANSMITTER ENERGIZING CIRCUIT

e.m.f. of 4 V: the external load for maximum power transfer now being an equal impedance of 100 apparent ohms (Fig. 76(*b*)). In the a.c. case, however, the angle of the impedance must also be considered. It can be shown that if a source of a.c. has an internal impedance with a lagging angle of ϕ, the maximum power is delivered if the external

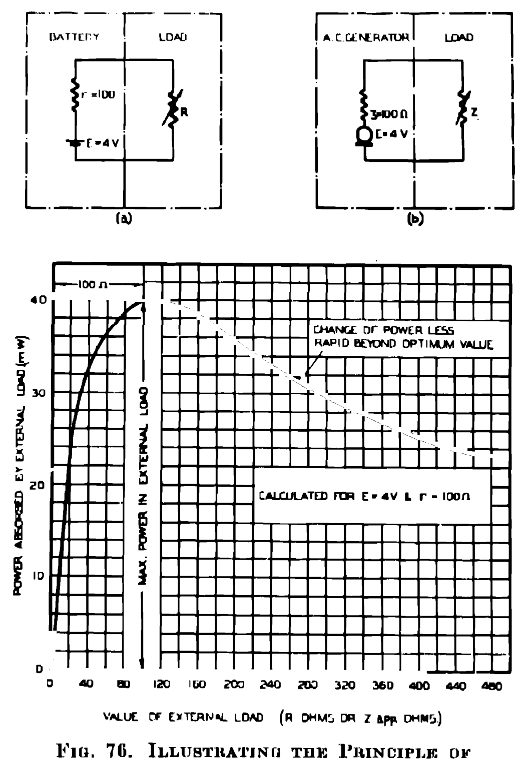


FIG. 76. ILLUSTRATING THE PRINCIPLE OF IMPEDANCE MATCHING

impedance is equal in magnitude but has a *leading* angle of ϕ—or vice versa.

A telephone transmitter is essentially a generator of alternating current of voice frequency and can be considered exactly as an a.c. generator having a given internal impedance and producing a certain e.m.f. dependent upon the d.c. energizing direct current and the intensity of the sound impinging upon the diaphragm. The speech energy in a telephone system is small, and it is very desirable to obtain the maximum transfer of energy by *matching* the transmitter and line impedances. If exact matching is not possible, it is preferable that the line impedance should be slightly greater than the transmitter impedance rather than vice versa. This is illustrated in Fig. 76 which shows that, when the load resistance is plotted on a linear scale, the fall of power is less rapid beyond the optimum value than before it.

Mathematical Analysis. The conditions necessary for the maximum transfer of power in an a.c. circuit can be shown mathematically as follows:

If the e.m.f. of a generator is E and its internal impedance is Z_s, the current into an external load Z_r is given by:

$$I = E/(Z_s + Z_r) \quad . \quad . \quad . \quad . \quad (1)$$

The power delivered to the external load is $= I^2 Z_r$

i.e. $$P = \left(\frac{E}{Z_s + Z_r}\right)^2 \times Z_r$$

or $$= E^2 Z_r/(Z_s + Z_r)^2 \quad . \quad . \quad . \quad (2)$$

The rate of change of power with respect to the value of Z_r can be obtained by differentiating, thus

$$\frac{dP}{dZ_r} = \frac{E^2(Z_s + Z_r)^2 - 2E^2 Z_r(Z_s + Z_r)}{(Z_s + Z_r)^4}$$

$$= \frac{E^2(Z_s + Z_r) - 2E^2 Z_r}{(Z_s + Z_r)^3}$$

$$= \frac{E^2 Z_s + E^2 Z_r - 2E^2 Z_r}{(Z_s + Z_r)^3}$$

$$= \frac{E^2(Z_s - Z_r)}{(Z_s + Z_r)^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The maximum power occurs when the slope of this curve is zero, i.e.

$$dP/dZ_r = 0$$

Equating (3) to zero

$$\frac{E^2(Z_s - Z_r)}{(Z_s + Z_r)^3} = 0$$

from which

$$Z_s - Z_r \text{ must be } 0;$$

i.e. for maximum power in the load

$$Z_s = Z_r \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If, now, Z_s is divided into its resistive and reactive components R_s and X_s and similarly Z_r is divided into R_r and X_r, then substituting in the power equation (2):

$$P = \frac{E^2(R_r + jX_r)}{(R_s + jX_s + R_r + jX_r)^2}$$

For the maximum power it is apparent that the denominator should be a minimum. This will only occur if:

$$jX_s = -jX_r$$

i.e. when $$X_s = -X_r$$

Thus, for the maximum power transfer, the sending and receiving impedances must be equal in magnitude and opposite in angle,

i.e. $$Z_s \underline{/\phi} = Z_r \overline{/\phi}$$

Use of Transformers for Impedance Matching. Reverting again to Fig. 73, it is clear that the maximum energy is passed to line when the impedance of the line and distant receiver together is equal to the internal impedance of the transmitter. The line impedance varies of course with the composition and length of line and, when a telephone may be connected to lines of different impedance, the best that can be done is to match the impedance for an average line. Now, the average impedance of the lines and terminal equipment in a public telephone system is normally many times greater than the internal impedance of a transmitter. The impedance of the latter is largely determined by its ohmic resistance, and any increase in the resistance must be accompanied by a corresponding increase in the battery e.m.f. Even, if this were economically practicable it would be difficult to design a transmitter of comparable impedance to that of an average line. Since it is not possible to match the impedance of the transmitter and line by direct design, correction of impedance must be made by the method of *coupling* the transmitter to the line.

It has been shown (Fig. 76) that, with a transmitter impedance of 100 Ω, the maximum power is delivered to the line when the line impedance is also 100 Ω. When the transmitter e.m.f. is 4 V, this maximum power is 40 mW and the p.d. across the line is

$$\sqrt{(\text{impedance} \times \text{power})} = \sqrt{(100 \times 0{\cdot}04)} = 2 \text{ V}.$$

If now the line impedance is raised to say 400 Ω, this same maximum power of 40 mW can be obtained if the p.d. across the line is increased to

$$\sqrt{(400 \times 0{\cdot}04)} = 4 \text{ V}.$$

Hence, if a means can be found of increasing the p.d. applied to the line from 2 to 4 V, without

interfering with the current in the transmitter, it is possible to obtain the maximum transfer of energy from a 100 Ω transmitter to a 400 Ω line. These conditions can be met by the introduction of a transformer between the transmitter and line such that the voltage ratio of the primary and secondary windings is 2 : 4 or 1 : 2.

Assume as in Fig. 77 that the impedance of the line and distant apparatus is Z_s apparent ohms and that the line is coupled to the transmitter by a

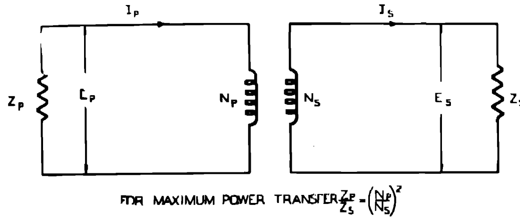


FIG. 77. USE OF A TRANSFORMER FOR MATCHING THE IMPEDANCE OF TWO CIRCUITS

transformer having N_p and N_s turns on the transmitter and line sides respectively. Let the impedance of the line as measured from the transmitter side of the transformer be Z_p and similarly let the voltages and currents be as shown. The ratio of the primary and secondary voltages of a transformer depends upon the turn ratio of the two windings:

i.e. $$E_s/E_p = N_s/N_p \quad . \quad . \quad . \quad . \quad (1)$$

If it is assumed that no power is lost in the transformer:

Power input to primary = power output from secondary

or $$E_p \times I_p = E_s \times I_s \quad . \quad . \quad . \quad . \quad . \quad (2)$$

but $$I_p = E_p/Z_p \text{ and } I_s = E_s/Z_s \quad . \quad (3)$$

Substituting for I_p and I_s in (2)

$$E_p^2/Z_p = E_s^2/Z_s$$

From which, $Z_p/Z_s = (E_p/E_s)^2$

Or, from (1), $Z_p/Z_s = (N_p/N_s)^2$

and $Z_p = Z_s \times (N_p/N_s)^2$

or $N_s/N_p = \sqrt{(Z_s/Z_p)}$.

Thus the impedance of the line, as seen from the transmitter, can be made any value to suit the internal impedance of the transmitter by so choosing the primary-to-secondary turn ratio that this ratio when squared and multiplied by the line impedance is equal to the internal impedance of the transmitter. To illustrate, if it is desired that a line of 600 Ω should be coupled to a transmitter of, say, 67 Ω impedance, a transformer having a turn ratio (secondary to primary) of $\sqrt{(600/67)} = 3 : 1$ approximately should be used. The above considerations apply not only to the coupling of a transmitter to a line but also in many circumstances where two circuits of different impedances must be coupled together. Hence the principle of impedance matching may be summarized as follows:

Whenever two circuits are to be coupled together to give the maximum transfer of energy from one to another, then the turn ratio of the coupling transformer must be such that

$$\frac{\text{Turns on winding connected to circuit } A}{\text{Turns on winding connected to circuit } B} = \sqrt{\frac{\text{impedance of } A}{\text{impedance of } B}}.$$

Local Battery Telephone with Induction Coil. Fig. 78 shows a unidirectional telephone circuit employing a transformer for coupling the transmitter circuit to line. It will be noted that in addition to its function of impedance matching, the transformer also isolates the d.c. transmitter current in a local circuit and at the same time prevents direct current from passing to line. The transformer normally used is of the "induction coil" type with an open core as described in Chapter IV. It has a low resistance primary of 1 Ω and a secondary of 25 Ω. The low resistance primary winding reduces the d.c. power absorbed by the winding to a minimum and so enables the required transmitter current to be provided by a low voltage battery. The battery, incidentally, usually consists of two Leclanché cells in series

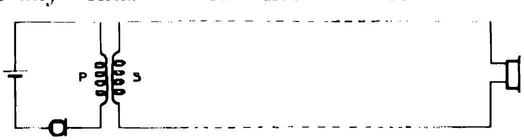


FIG. 78. UNIDIRECTIONAL TELEPHONE CIRCUIT WITH INDUCTION COIL

which give a nominal e.m.f. of 3 V. The secondary/primary turn ratio is in the order of 5/1 which provides correct impedance matching when the line impedance is some 25 times that of the transmitter. Fig. 79 is a further development arranged to provide for simultaneous conversations in both directions and is the basic circuit of all local battery telephones.

It would perhaps be of advantage at this stage to review the energy transformations which occur during a conversation with two local battery telephones (Fig. 79). When the subscriber at station A speaks into his transmitter, the sound waves impinging on the diaphragm of the latter

produce a corresponding mechanical vibration. Thus a portion of the original sound energy is transferred to the kinetic and potential energy of the vibrating diaphragm. Some of this energy is expended in overcoming mechanical forces within the diaphragm itself, whilst the remainder is utilized to stress the granules of the transmitter—to control the very much greater energy of the battery current.

The alternating line current passes through the coils of the distant receiver, a certain amount of energy being lost due to the presence of the induction coil with its closed primary circuit. An alternating flux is produced in the pole-pieces of the re-

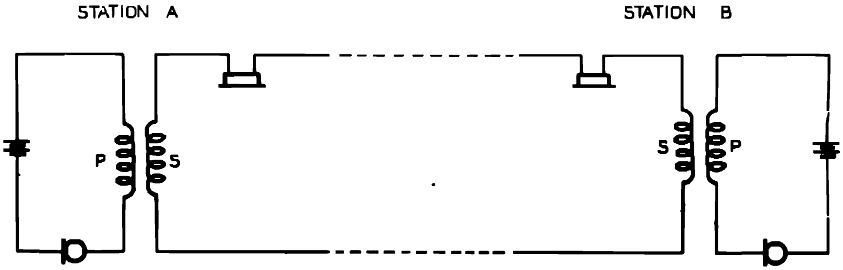


FIG. 79. BOTHWAY LOCAL BATTERY TELEPHONE CIRCUIT WITH INDUCTION COILS

the energy being ultimately dissipated as heat in overcoming the frictional resistance of the granules. The variation in pressure on the granules results in corresponding variations in the resistance of the transmitter and so in the value of the current in the transmitter circuit. The fluctuating direct current in the primary circuit expends energy in overcoming the resistance of the circuit (I^2R losses), but the alternating component of this current in passing through the primary of the induction coil produces a variable flux in the core of the coil. The variable flux due to changes in the value of the primary current, links with the turns of the secondary winding and thereby induces into it an alternating e.m.f. When the secondary circuit is closed by the line and distant telephone, current flows as a result of the induced e.m.f. and the magnetic energy of the fluctuating field thus appears in the form of an alternating current in the line. It is important to realize that the electrical energy transmitted to the distant telephone is not derived from the original sound-wave. The energy of the latter is used up entirely in the transmitter, but is there utilized as a form of valve

ceiver and, in conjunction with the static field of the permanent magnet, gives a variable tractive force on the receiver diaphragm. The energy thus imparted to the diaphragm is in turn given up partly to overcome the mechanical forces in the diaphragm and partly to produce sound-waves in the adjacent air.

Conditions for Maximum Power in Receiver. So far the use of an induction coil to obtain the maximum transfer of power from a transmitter circuit to line has been considered. Assuming that the conditions are adjusted at the outgoing end for the maximum energy transfer to line, then it is desirable also that arrangements be made at the incoming termination to utilize as much as possible of this energy. In Fig. 79 the line impedance and the impedance of the distant receiver are virtually in series, and it is apparent that the energy available in the receiver depends upon the ratio of its impedance to that of the line.

In the earlier types of local battery telephones, no special arrangements were made to adjust the impedance of the receiver circuit, reliance being placed on a receiver of fairly high impedance

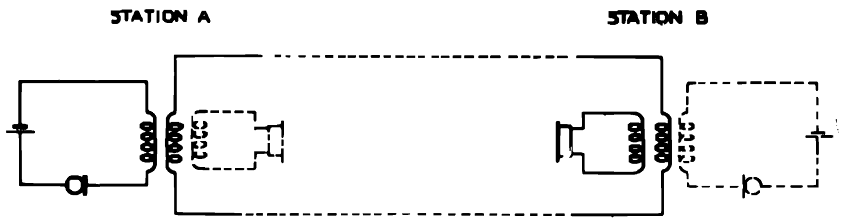


FIG. 80. USE OF A THIRD WINDING ON INDUCTION COIL TO MATCH THE RECEIVER AND LINE IMPEDANCES

placed directly in the line circuit. In modern circuits, however, a higher efficiency is obtained by matching the receiver impedance to that of the line by the use of additional induction coil windings. Fig. 80 shows the arrangement in principle; the full lines representing the requirements for unidirectional working, whilst the broken connexions

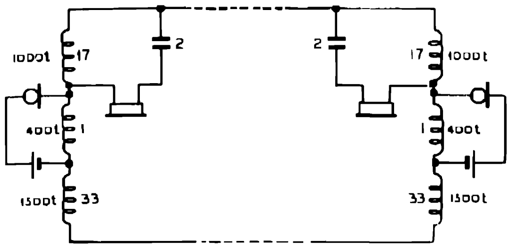


FIG. 81. LOCAL BATTERY TELEPHONE CIRCUIT WITH THREE-WINDING INDUCTION COIL CONNECTED AS AN AUTO-TRANSFORMER

show the additions necessary for transmission in both directions. In the practical circuit, a three-winding induction coil is necessary.

The voice frequency energy from the transmitter circuit is applied to line via the induction coil which is so designed to match the impedance of the line plus distant telephone with that of the local telephone circuit. At station B the line and receiver windings of the induction coil are of such a ratio that the impedance of the receiver is matched to that of the line plus originating telephone, thereby obtaining a maximum transfer of energy from the line to the receiver circuit.

Modern Local Battery Telephone Circuit. Fig. 81 illustrates the principles just described as applied to a modern local battery telephone circuit. A three-winding induction coil is used to give impedance matching between the transmitter and line and between the line and receiver, but on account of signalling requirements and in order to minimize the size of (and also the losses in) the induction coil, the windings are coupled on an auto-transformer basis. The principle of the auto-transformer is shown in Fig. 82 (*a*). Alternating current flowing in winding N_1 produces an alternating flux in the core of the transformer which cuts the turns of both windings N_1 and N_2 to produce an e.m.f. of a magnitude equal to that which would be produced in a separate secondary winding consisting of $N_1 + N_2$ turns. The transformer is therefore equivalent to the one shown at (*b*). Under circumstances where there is no objection to a metallic

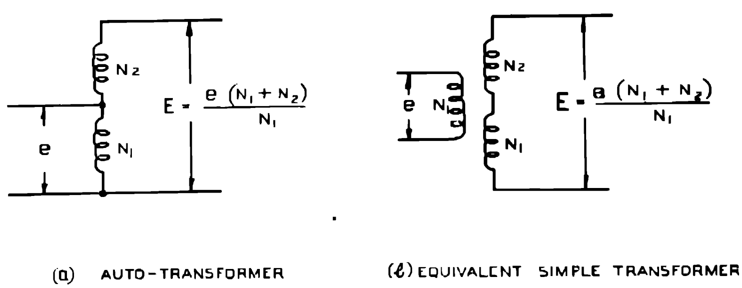


FIG. 82. PRINCIPLE OF THE AUTO-TRANSFORMER

connexion between the primary and secondary windings, the auto-transformer has advantages in requiring a smaller total number of turns.

Reverting to Fig. 81, the effective turn ratio of the induction coil for coupling the line to the transmitter is 1500 + 400 + 1000 to 400, i.e. 7/1 approximately. Similarly, at the receiving end, the turn ratio of the line/receiver windings is 1500 + 400 + 1000 or 3/1 approximately. The 2 μF condenser inserted in the receiver circuit prevents d.c. signalling current from traversing the receiver, whilst the 1 Ω primary winding of the induction coil provides a transmitter excitation circuit of low ohmic resistance.

Central Battery Transmission. Local battery telephones have now been largely superseded in modern telephone systems except for point-to-point circuits and for lines of exceptionally high resistance. The provision of a local battery at each telephone involves not only a high initial cost but also very appreciable maintenance charges and a high liability to faults. It is, moreover, difficult to obtain a uniform standard of transmission, since the sending efficiency of each transmitter varies month by month in accordance with the changing condition of the primary battery. As an alternative to the provision of local batteries at each telephone, a battery common to all telephones can be located at some central point (generally the exchange) and the energizing current for the subscribers' transmitters can be fed over the speaking pair to each individual telephone. In order to supply the requisite current to each transmitter, through an external line of appreciable resistance, the central battery must necessarily be of high voltage. This battery is also used for signalling purposes and is almost invariably made up of secondary cells of large capacity.

With central battery transmission the line resistance determines to a large extent the value of the transmitter energizing current and hence the sending efficiency of the instrument. This factor places a definite limitation on the permissible line

resistance. Moreover, the system of supplying battery to line must ensure that the transmitter current on long lines is adequate without, at the same time, providing an excessive current on short lines.

Central Battery Telephone Circuit. The most elementary circuit for central battery (abbreviated

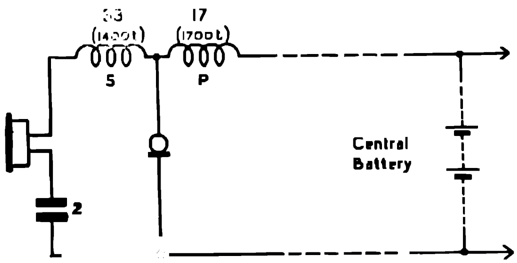


FIG. 83. SIMPLE TELEPHONE CIRCUIT WITH TRANSMITTER ENERGIZED FROM A CENTRAL BATTERY

C.B.) transmission consists of a transmitter and receiver in series applied direct to the line. Such a scheme makes no provision for matching the impedance of the transmitter to line and allows an undesirable direct current to pass through the receiver. A more practical arrangement, which was for many years standard on all systems of C.B. transmission, is shown in Fig. 83. The connexions of the two-winding induction coil are somewhat similar to the auto-transformer already considered, except that the primary circuit now includes the external line and the secondary circuit is local. Fig. 84 shows the paths of the alternating speech currents somewhat more clearly. For simplicity, the circuit of the receiver and condenser at the sending telephone has been shown as an impedance Z_1, and similarly the transmitter at the receiving telephone has been shown as Z_2. The excitation of the transmitter at the sending telephone produces an e.m.f. of speech frequency at the transmitter terminals. The transmitter voltage (e_1) gives rise to a circulating current (i_1) in the local circuit containing the secondary of the induction coil, the receiver and the condenser. This current in turn produces a p.d. (e_2) across the secondary winding of the induction coil, the phase and magnitude of which depends upon the values of e_1, Z_1 and the impedance loading of the primary winding. The induction coil windings are so connected that the passage of the current through the secondary coil induces an e.m.f. (e_3) into the primary winding which is additive to e_1 and so applies a boosted voltage ($e_1 + e_3$) to line. Ideally, e_1 and e_3 should be substantially in phase to obtain the maximum voltage to line. In practice the current in the secondary circuit (i_1) lags some 45° behind e_1 (Fig. 85) and, allowing for the normal phase difference between the primary current and secondary volts in an induction coil, the induced voltage e_3 lags slightly behind e_1. The vector sum of e_1 and e_3 does nevertheless give an effective voltage to line appreciably greater than that of the transmitter alone.

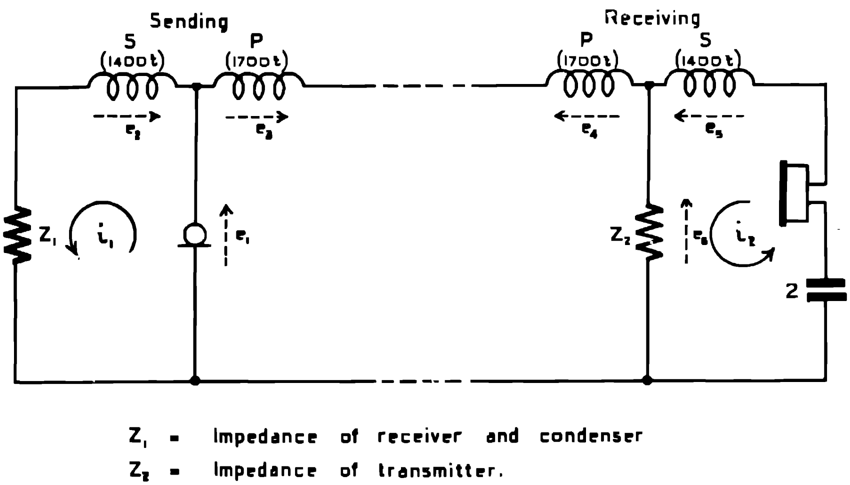


FIG. 84. SPEECH VOLTAGES AND CURRENTS IN A C.B. TELEPHONE CIRCUIT

The action of the circuit during speech reception is illustrated in the right-hand portion of Fig. 84. By far the larger portion of the received speech currents pass through the low-impedance transmitter (Z_2) rather than through the receiver circuit which is of much higher impedance. The current, in passing through the primary winding of the induction coil, induces an e.m.f. (e_5) in the secondary

winding which in turn produces a local circulating current (i_2) in the receiver circuit.

The induction coil now behaves as a step-down transformer to match the impedance of the receiver circuit to that of the line. It is apparent that, since the induction coil has a different function under transmitting and receiving conditions, the turn ratio of the primary and secondary windings must be a compromise to give reasonable sending and receiving efficiencies. The passage of the incoming line current through the transmitter (Z_2) produces a p.d. (e_6) in the receiver circuit which opposes the induced e.m.f. in the secondary winding. This transmitter p.d. (e_6) is out of phase with the voltage induced in the secondary circuit (e_5) and is not of great magnitude if the impedance of the transmitter is reasonably low.

Sidetone. Sidetone may be defined as the reproduction in a speaker's telephone receiver of sounds picked up by his transmitter. In all the telephone circuits so far considered some part of the transmitted energy is absorbed by the local receiver circuit, and the recent improvements in the performance of transmitters and receivers has consequently resulted in a corresponding increase in the volume of sidetone.

The psychological effect of sidetone is important. The most comfortable conditions for the user of a telephone occur when the volume of his own speech in the local receiver is approximately equal to the volume obtained at the free ear by direct air propagation of the speech waves. If sidetone is entirely eliminated, the telephone appears to be

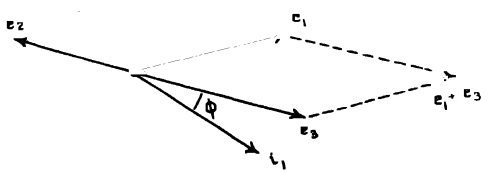


FIG. 85. ELEMENTARY VECTOR DIAGRAM OF THE VOLTAGES AND CURRENTS IN A C.B. TELEPHONE CIRCUIT

"dead" but, on the other hand, excessive sidetone is not only irritating but also causes the speaker involuntarily to lower his voice with the resultant degradation of transmission efficiency. From recent research into the reactions of a number of people to varying degrees of sidetone, it has been shown that with a simple C.B. telephone (Fig. 83) a reduction of 15 db in the volume of sidetone causes the speaker to raise his voice by about 5 db. Similarly if the volume of sidetone is increased by 10 db the speaker reduces his voice by approximately 6 db.

The same tests have shown that this effect is substantially independent of the volume of room noise, although for higher values of room noise (say up to 75 phons) there is a tendency for the speaker to raise his voice by as much as 3 db. It is perhaps somewhat surprising to note that the volume used by a speaker is not measurably affected by the volume he receives from the distant end.

As a result of these disclosures the majority of new telephone circuits are provided with some

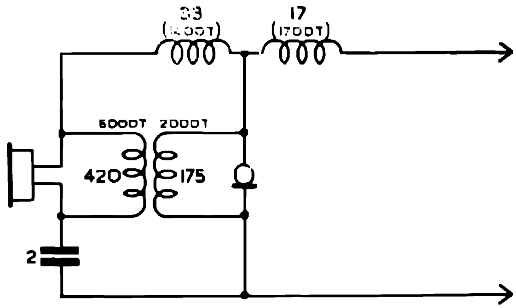


FIG. 86. REDUCTION OF SIDETONE BY MEANS OF SUBSIDIARY TRANSFORMER

means of reducing the volume of sidetone. Unfortunately it is almost impossible to reduce the sidetone without reducing to some degree the transmission efficiency of the circuit, but with careful design, the loss of efficiency can be reduced to such a value that it is outweighed by the advantages accruing from the reduction in sidetone.

Reduction of Sidetone by Subsidiary Transformer. Reverting to the original auto-transformer coupled circuit of Fig. 83, it will be observed that the whole of the current in the local secondary circuit traverses the receiver when the transmitter is excited. The volume of sidetone with this circuit is consequently high. Some improvement in sidetone could be made by shunting away some of the current from the receiver, but this would merely degrade the reception efficiency of the instrument. Fig. 86 shows an adaptation of the original circuit with an additional transformer for the reduction of sidetone. This arrangement was, until recently, the standard circuit for C.B. telephones using hand-microphones with high-efficiency transmitters and receivers. Although it is now superseded by the circuit to be considered later, there are nevertheless many thousands of such circuits in use to-day.

The subsidiary anti-sidetone coil is connected with its two windings directly across the transmitter and receiver respectively, and the connexions are such that during the transmission of speech an e.m.f. is applied to the receiver which is equal and

opposite to the normal p.d. across it. If, for example, at some particular instant, the current in the secondary circuit is 2 mA, its effect can be neutralized by arranging that the subsidiary transformer passes 2 mA through the receiver in the opposite direction. The 175 Ω winding is connected directly across the transmitter and, with a given transmitter output, the e.m.f. induced in the 420 Ω winding is substantially independent of the impedance of the line to which the telephone is connected. The normal current in the receiver is, however, largely determined by the value of the line impedance, and hence full sidetone suppression will occur only for one critical value of line impedance. The anti-sidetone coil is designed to provide as much sidetone correction as possible on a line of *average* impedance, and where lines differ from this average the degree of sidetone compensation is necessarily lower. The presence of the additional coil introduces transmission losses, partly on account of the direct current shunting of the transmitter and partly due to the absorption of voice frequency a.c. energy in the transmitter and receiver circuits, but by careful design this loss is not excessive.

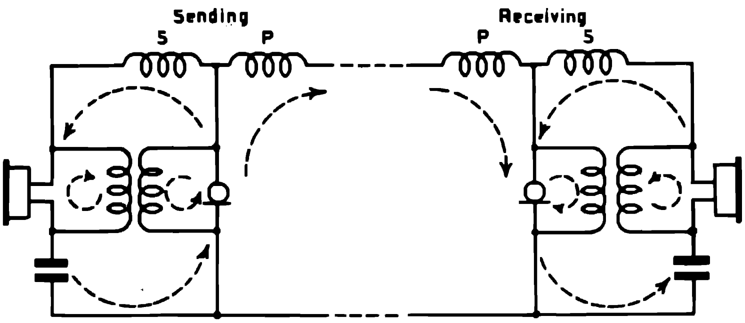


FIG. 87. RELATIVE DIRECTIONS OF CURRENTS DURING SENDING AND RECEIVING

During reception of speech, the e.m.f. induced in the secondary winding of the induction coil is in the opposite direction to the p.d. across the transmitter. Hence, the normal secondary current and the current from the subsidiary transformer are in the same direction through the receiver. The subsidiary transformer does not, therefore, degrade the receiving efficiency of the telephone. The different conditions during sending and receiving are illustrated in Fig. 87, the arrows indicating the relative directions of the currents in each part of the circuit.

Anti-sidetone Induction Coils. The latest type of telephone circuit employs an entirely different method of sidetone suppression. In Fig. 88 (*a*) a three-winding transformer or induction coil is connected to two impedances Z_A and Z_B and a source of alternating e.m.f. is applied as shown. Current from the generator flows through windings P_1 and P_2 in opposite directions, the value of the two currents being dependent upon the values of Z_A and Z_B. If, now, Z_A is made equal to Z_B, the currents in P_1 and P_2 must also be equal. Under these conditions it is possible by making P_1 and P_2 identical as regards the number of turns, etc., to arrange that the magnetic effect of P_1 exactly neutralizes that of P_2, thereby avoiding any induced e.m.f. in the secondary circuit S. If Z_A and Z_B differ slightly, then the magnetic effects of P_1 and P_2 do not exactly neutralize, and an e.m.f. is induced in the secondary circuit of a magnitude depending upon the degree of unbalance between Z_A and Z_B. In the lower figure, (*b*), the a.c. generator is replaced by impedance Z_C, and an e.m.f. is introduced in series with Z_A. The current from the generator flows through P_2 and a portion also passes through P_1. The currents in P_1 and P_2 are now in the same direction and their magnetic effects assist to produce a high value of induced e.m.f. in the secondary circuit.

If, now, a telephone circuit could be so arranged that the transmitter and receiver occupy the same

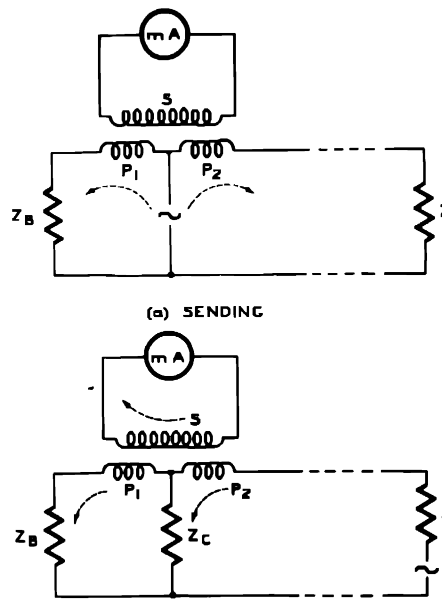


FIG. 88. PRINCIPLE OF THE BALANCED TRANSFORMER

positions as the generator (or Z_C) and the milliammeter respectively, the suppression of sidetone on transmitted speech would be obtained without degradation of incoming speech. To meet these conditions it is necessary to provide a local impedance network (Z_B) which is equal to that of an average line together with the distant telephone (Z_A).

The theoretical application of the balanced transformer principle to a C.B. telephone is shown in Fig. 89. As in the original C.B. telephone circuit (Fig. 83), the induction coil windings (P_1 and P_2 of Fig. 89) are arranged as an auto-transformer to match the transmitter impedance to that of the line, whilst the receiver is now placed in a local secondary circuit. The 2 μF condenser is inserted primarily to avoid the d.c. shunting of the transmitter, but together with winding P_1 forms the impedance network, which, for the elimination of sidetone, must be equal to that of an average line. If the impedance of this local circuit can be made equal to the line impedance, then the currents in P_1 and P_2 balance out in their effect on the secondary circuit. Unfortunately there are practical difficulties in this simple arrangement. Firstly, windings P_1 and P_2 cannot be made identical since their ratio is determined by impedance matching considerations. Allowance for any difference in the two windings can of course be met by a corresponding correction to the impedance of the local circuit. The latter impedance is made up of the

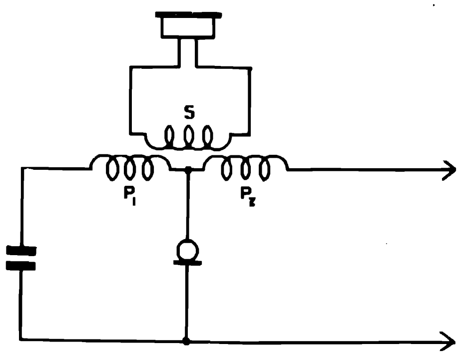


FIG. 89. APPLICATION OF THE BALANCED TRANSFORMER PRINCIPLE TO A C.B. TELEPHONE

capacitative reactance of the condenser and the ohmic resistance and inductance of P_1.

An average subscriber's line has an impedance of some 500 Ω with a leading (capacitative) angle of about 45°. To balance the reactive component of the line impedance, the condenser in the local circuit must have a capacitance of the order of 0·25 μF. Thus, the normal 2 μF condenser of a subscriber's instrument (which is required for signalling purposes) is too large, and when inserted in the local circuit makes it difficult to obtain a reasonable balance—especially on short lines and at low frequencies. The provision of a second condenser in a telephone circuit is undesirable on economic grounds and the difficulty is in practice overcome by a slight modification to the circuit.

Fig. 90 shows the final transmission circuit which is now standard and is known as the

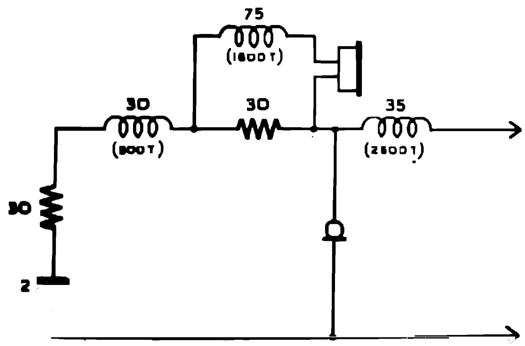


FIG. 90. PRACTICAL A.S.T.I.C. TELEPHONE CIRCUIT

A.S.T.I.C. (Anti-Side-Tone-Induction-Coil) telephone. The induction coil now contains, in addition to the three inductive windings, two further non-inductive resistances. The 30 Ω resistance adjacent to the condenser is provided to meet signalling conditions and from a transmission aspect may be considered as part of the 800 turn winding. The second resistance of 30 Ω is also placed in the local circuit and is of such a value that the p.d. across it is equal to the e.m.f. induced in the 75 Ω winding due to out-of-balance conditions resulting from the use of the 2 μF condenser. In effect, the difficulty of obtaining a balance in the induction coil windings themselves is overcome by introducing a p.d. into the receiver circuit which is equal and opposite to the e.m.f. induced in the secondary circuit due to the out-of-balance.

Operator's Telephone Circuit. Suppression of sidetone is particularly important in operator's instrument circuits where a telephonist is required to wear a headset for prolonged periods under conditions of fairly intense room noise. Fig. 91 shows the basic element on which most operator's instrument circuits are designed. The transmitter is connected in series with the 4 Ω primary winding of the induction coil, and the transmitter energizing current is obtained from the main exchange battery through a retard coil which reduces the voltage applied to the transmitter to the correct value, and also offers a high impedance to the passage of speech currents through the main battery. The

4 μF condenser provides an alternative low impedance path for the speech currents in the primary circuit. The induction coil has two secondary windings which are connected in series to the tip and ring conductors of the cord circuit. The receiver is connected across one of the two secondary

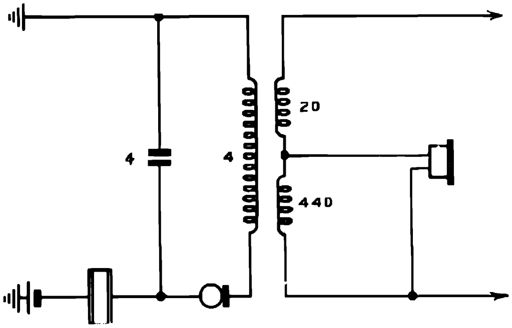


FIG. 91. OPERATOR'S INSTRUMENT CIRCUIT WITH SIDETONE SUPPRESSION

windings. The turn ratio of the secondary windings is so arranged that when the telephone circuit is connected to a line of average impedance, the voltage drop across the receiver is neutralized by an equal and opposite p.d. from the 440 Ω winding. The conditions can perhaps be better visualized from Fig. 92. E_{S1} is the voltage induced in the 20 Ω secondary winding while E_{S2} is the comparable voltage in the 440 Ω winding. The impedances of the secondary windings are shown by Z_{S1} and Z_{S2} respectively. If, now, Z_L is the impedance of the

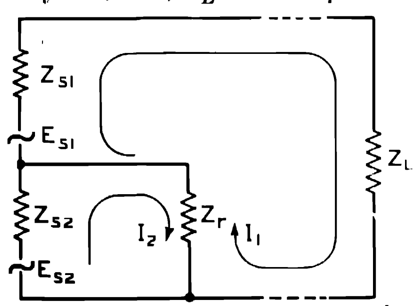


FIG. 92. VOLTAGES AND CURRENTS IN OPERATOR'S ANTI-SIDETONE TELEPHONE CIRCUIT

average connexion to which the telephone circuit can be switched, and Z_r is the impedance of the receiver itself, the voltages are adjusted so that the main line current I_1 is exactly neutralized through Z_r by the local current I_2. Under these ideal conditions there is no sidetone in the operator's receiver but there is of course some small degree of sidetone when the circuit is connected to lines which differ from the average impedance. The arrangement does nevertheless provide a very satisfactory means of sidetone reduction.

Acoustic Shocks. In any telephone system there is always the possibility of abnormal surge voltages being applied to a telephone receiver. Such voltages persist for such a short time that no appreciable harm is done to the receiver itself or to the associated equipment, but the resultant click is extremely unpleasant for anyone using the receiver and may, in fact, cause temporary or permanent injury to the ear. The increase in the efficiency of receivers, coupled with the adoption of more and more complex switching arrangements, has aggravated the difficulty and special arrangements are now made on all operators' telephone circuits to guard against acoustic shocks.

It is desirable that any device intended to prevent acoustic shocks should absorb the energy of any abnormal surge voltage, but at the same time it should not introduce any appreciable transmission

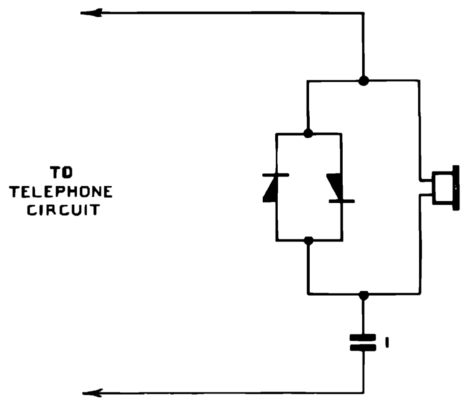


FIG. 93. USE OF RECTIFIERS TO PREVENT ACOUSTIC SHOCKS

loss for speech voltages of normal amplitude. The arrangement employed consists of two single-element copper-oxide rectifiers joined in opposite directions across the receiver as shown in Fig. 93. The resistance characteristics of the copper-oxide rectifier have already been considered in Chapter IV (Fig. 51). If an alternating voltage of less than, say, 0·1 V peak is applied to the rectifier in its conducting direction, the resultant current is negligible, but if the voltage is increased, say, to 0·3 V, the rectifier resistance becomes very small. With two such rectifiers connected in parallel but with opposite polarity, rectifier current flows for both the positive and negative half-cycles. If then the combination of rectifiers is connected across a telephone receiver, the energy of any excessive applied voltage—in either direction—is diverted through the rectifiers, only a small portion passing

through the receiver. For normal speech voltages, however, the shunt loss introduced by the rectifier is negligible and the rectifiers do in fact act as a voltage limiting device across the receiver. As each half of the rectifier consists of a single element only, great care is necessary in the circuit design to prevent the application of d.c. potentials which would overheat and destroy the rectifiers. In general, this protection is provided by a 1 μF condenser in series with the rectifiers and receiver.

Rectification of Radio Frequencies. It has been found that telephones in the vicinity of high-power radio transmitters occasionally suffer from disturbance due to the radio transmissions. The main cause of such interference is the rectifying action of the carbon transmitter in the telephone circuit. The carbon granules in fact form an elementary crystal detector for the rectification of the radio-frequency signals. In order to prevent this trouble and to provide a safeguard against possibly greater difficulties in the future, all modern telephone circuits are provided with an 0·1μF non-inductive condenser connected across the terminals of the transmitter. This condenser effectively by-passes the radio frequencies and so reduces interference to a minimum.

Transmission Bridge. When two telephone circuits are connected together, the circuit at the common point is usually required to provide a ready path for the speech currents from one line to the other whilst at the same time separating the two lines from a signalling point of view. It is, moreover, necessary to supply signalling and/or transmitter current to the lines with a minimum of interference to the speech circuit. The circuit element at which this segregation occurs is known as the *transmission bridge*.

A simple transmission bridge to supply transmitter current to two central battery telephones is illustrated in Fig. 94. The battery, which may in practice range from 22 V to 50 V, is connected in series with an impedance coil across the speaking conductors, the current dividing more or less equally to the two telephones. The impedance coil is inserted primarily to avoid the shunting away of the alternating speech currents through the battery. Apart from the serious transmission loss which would result from such a shunting effect, it is undesirable to permit speech currents to pass through the battery owing to the variable p.d.s which would be set up across the battery, with the resulting tendency to overhearing between circuits. Moreover, the inclusion of a high impedance in the battery supply is essential to avoid transmission to the speaking conductors of any slight variations in the p.d. of the battery due to changes of current, capacitative and inductive surges, etc., resulting from signalling.

Signalling requirements necessitate that one pole of the battery should be connected to earth, and it is the standard practice in this country to earth the positive pole. With the single impedance coil

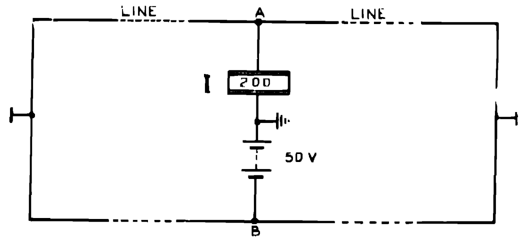


FIG. 94. ELEMENTARY TRANSMISSION BRIDGE WITH ONE IMPEDANCE ELEMENT

transmission bridge, the capacitance and insulation of the battery to earth, and particularly the introduction of the earth connexion itself, produce an electrical unbalance of the speaking conductors, i.e. the impedance of the A-line to earth is very much greater than the impedance of the B-line to earth. It is a fundamental rule in telephony that both conductors of a speaking pair should, as far as possible, have the same electrical characteristics. Each line of a pair should not only have the same ohmic resistance but the capacitance of each line to earth must also be the same. Furthermore, each wire must have the same degree of electrostatic and electromagnetic coupling with other nearby conductors. Failure to obtain a high degree

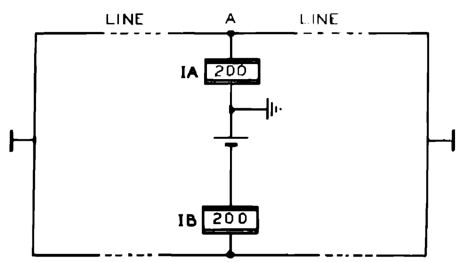


FIG. 95. SIMPLE TRANSMISSION BRIDGE WITH BALANCED IMPEDANCE COILS

of balance results in the introduction of undesirable noises and tends to produce overhearing between circuits.

A more practical arrangement, using two impedance coils, is given in Fig. 95. The impedance of each line to earth has now been equalized by the introduction of the two coils (IA and IB) which have identical impedance characteristics. The impedance of each element is, moreover, so great

that the unbalanced earth connexion at the battery is effectively isolated from the lines. This transmission bridge does not provide for the segregation of direct currents, but the circuit is quite suitable for an installation where all telephones are in the same building, e.g. as in a Private Branch Exchange. In such circumstances the resistances of all lines are of comparable magnitude and the current divides at points A and B more or

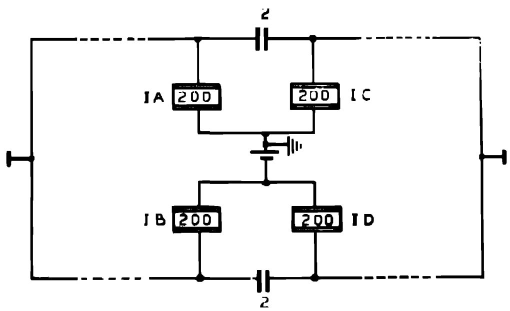


FIG. 96. STONE OR CONDENSER-IMPEDANCE TRANSMISSION BRIDGE

less equally to each telephone. If, however, as in a public system the resistance of lines varies considerably, a very unequal distribution of current would occur if a line of low resistance were connected to one having appreciably higher resistance. For example, if in Fig. 95 the p.d. of the battery is 50 V, and the two lines each have a resistance of 200 Ω, then the feed current to each transmitter is 50 mA. If now, a line of 60 Ω is connected to one of 300 Ω, the current in the two lines is approximately 93 mA and 18 mA respectively. The sending efficiency of a carbon transmitter varies considerably with the energizing current it receives, and hence to obtain any satisfactory degree of uniformity when lines of different resistance are connected together, arrangements must be made to supply the transmitter current independently to each telephone.

The Stone Transmission Bridge. If the circuit is to be split at the feeding point to provide separate direct current feeds to each telephone, it becomes necessary to introduce means for coupling the two lines together for the transmission of the voice-frequency speech currents, but at the same time to separate the two lines from a direct current aspect. There are two possible methods of coupling:

(*a*) Electrostatic coupling in which the two lines are connected for speech by large capacitance condensers.

or

(*b*) Electromagnetic coupling where a transformer is introduced between the two lines.

The usual method of electrostatic coupling known as a *Stone type transmission bridge,* is shown in Fig. 96. Four impedances are now required, the transmitter feeding current for one telephone being provided via IA and IB whilst the supply to the other telephone is taken via IC and ID. The impedance coils are of low resistance to meet the d.c. requirements, but their high impedance effectively prevents the passage of speech currents through the battery. The coils are, of course, accurately matched to balance the impedance to earth of the speech conductors. Whilst a ready path for the a.c. speech currents is provided by the series condensers, the two sides of the transmission bridge are completely isolated for direct currents. The coupling condensers are either of 2 μF or 4 μF capacitance, the latter being used on circuits where a particularly high standard of transmission is required. It is natural that the inclusion of two condensers in series with the speech path, together with the insertion of the four impedances across the circuit, should result in some transmission loss. In practice, however, the loss is only in the order of 1·2 db at 800 c/s, and is still further reduced to about 0·5 db when 4 μF condensers are used.

Generally, some or all of the impedance elements of a Stone transmission bridge are utilized also as electromagnetic relays for d.c. signalling purposes, and hence the coils are usually made up as relays. Sometimes, from a signalling point of view, it is essential to maintain separate magnetic circuits

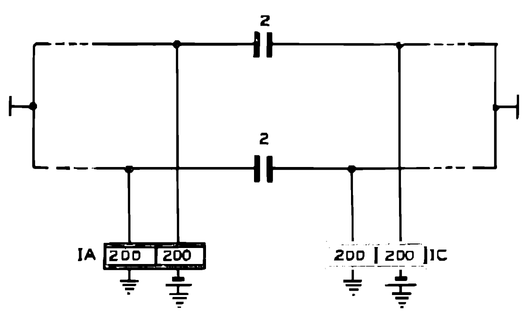


FIG. 97. STONE TRANSMISSION BRIDGE WITH COMBINED IMPEDANCE ELEMENTS

for IA, IB, IC and ID, but in other circumstances (notably in automatic switching circuits) it is permissible to associate the pair of impedances serving one line and to wind both coils on a common relay core as shown in Fig. 97. The two windings are, of course, connected so that they magnetically assist, and apart from cost considerations the combined arrangement is preferable (where permissible) on account of the better balance obtained by the mutual inductance of the two windings.

The Hayes Transmission Bridge. A common type of transmission bridge using electromagnetic coupling and known as the *Hayes bridge* is given in Fig. 98. Separate d.c. supply to each telephone is provided, whilst the four windings *A*, *B*, *C*, and *D* are wound on a common core as a transformer (or repeating coil) for voice-frequency currents. When the transmitter on the left is excited, alternating currents of voice frequency circulate through windings *A* and *B* via the battery. Changes of

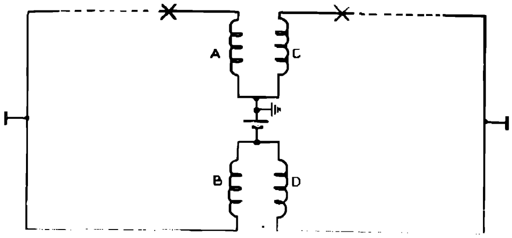


FIG. 98. HAYES TRANSMISSION BRIDGE

current in these two windings induce corresponding e.m.f.s in windings *C* and *D*, which in turn cause speech currents to circulate round the right-hand loop. Similarly, if the transmitter on the right is spoken into, the V.F. currents in *C* and *D* produce corresponding currents in the left-hand circuit. Apart from the fundamental difference between magnetic and electrostatic coupling, it is interesting to note that whereas in the Stone transmission system every effort is made to prevent speech currents from traversing the battery, in the repeating coil system the passage of speech currents through the battery is a basic requirement. The tendency to produce a variable p.d. across the battery due to the passage of speech currents, is counteracted to a large extent by so connecting the windings of the repeating coil that the voice-frequency currents, in say, *AB* and the resulting currents in *CD* traverse the battery in opposite directions thereby more or less neutralizing the effects of each other. The connexions of the repeating coil windings necessary to minimize the possibility of crosstalk due to changes in battery p.d. are such that the direct currents in the windings are additive in their magnetic effects. An alternative method would be to make the d.c. magnetic effects neutralize in the coil, but although this *subtractive* method enables a much smaller core to be used without danger of saturation, it is claimed that the *additive* method, apart from its advantage in minimizing changes in battery p.d., is less liable to overhearing between adjacent repeating coils owing to stray magnetic fields.

A repeating coil transmission bridge has a somewhat lower transmission loss (about 1 db) than the normal condenser-impedance bridge, but it is not so convenient when signalling is to be added to the transmission system. The repeating coil itself cannot be used for signalling, and relays must be added at the points marked X to receive the d.c. signals. This necessity adds to the total cost and, tends to increase the transmission loss. Moreover, great care must be exercised to avoid adding impedance to one line which would appreciably upset the balance of the speaking pair. Where a relay has to be included in series with one or other of the lines it is therefore usual to reduce its impedance to a minimum by shunting the coil by a large capacitance condenser or by a non-reactive resistor. There is, nevertheless, always some slight out-of-balance with a simple repeating coil bridge due partly to the signalling relays and partly to the unsymmetrical position of the earth connexion to the battery. On circuits where a high degree of balance is required, a modified arrangement as shown in Fig. 99 is used. An almost perfectly balanced d.c. supply is obtained by the introduction of impedances *IA*, *IB*, *IC*, and *ID* which, in practice, also serve as signalling relays. The circuit for the voice-frequency speech currents through the repeating coil windings is completed by the 2 μF (or 4 μF) condensers which also have the effect

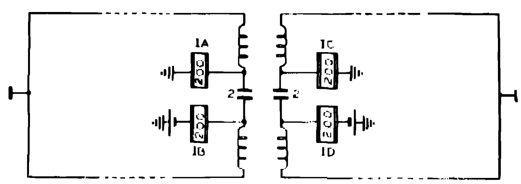


FIG. 99. BALANCED HAYES TRANSMISSION BRIDGE

of balancing out any slight impedance irregularities of the four coils.

Effect of Bridge on Transmission. It is interesting to examine the effects on transmission of the external line and the transmission bridge together. Fig. 100 shows the results of tests on a Stone type of transmission bridge connected to external lines consisting of 0·7 mile of 10 lb underground cable. It will be noted that the bridge and line together form a "band-pass" filter with heavy losses at the upper and lower extremes of frequency. The impedance coils have a small reactance (ωL) at low frequencies and the heavy shunt loss so introduced is exaggerated by the high series reactance of the condensers ($1/\omega C$). As the frequency increases, both the series and shunt losses fall, but beyond about 800 c/s the line capacitance commences to introduce a progressively greater attenuation. The substitution of 4 μF in place of 2 μF condensers slightly improves the low-frequency response, and

a reduction of the direct current through the impedance coils also helps slightly in this direction.

The loss curve for a transformer type bridge is substantially similar to the curve for the impedance bridge. Here, the high attenuation at low frequencies is due to the difficulty of obtaining a high

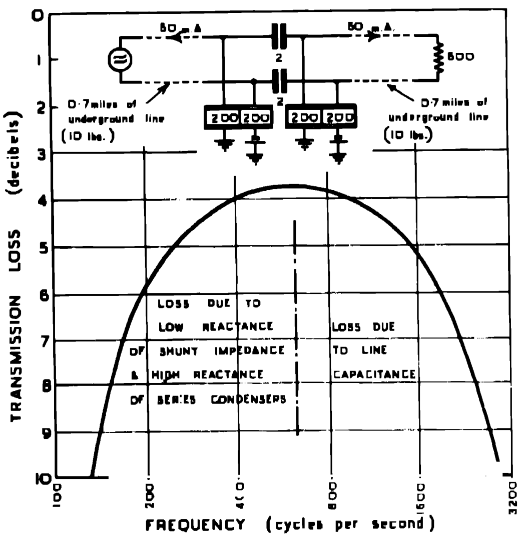


FIG. 100. LOSS INTRODUCED BY TRANSMISSION BRIDGE

winding inductance on a transformer which must carry direct current. The low-frequency loss of a transformer bridge is very largely determined by the quality of the transformer used and by the value of d.c. in its windings.

The effect of inserting two or more bridges in tandem should be noted. If, say, each bridge introduces a loss of 2 db at 1000 c/s, and 5 db at 300 c/s, there is a difference of 3 db between these frequencies with one bridge in circuit. With two bridges in tandem, the total loss at 800 c/s is 4 db, whilst the loss at 300 c/s is 10 db. There is, therefore, now a difference of 6 db. Thus, the degree of frequency distortion is doubled by the introduction of a second transmission bridge. The above is, however, true only when there is a line of appreciable impedance between the two bridges. If the transmission bridges are connected together without an intervening line (as in the Sleeve Control system) the total low frequency loss is much greater.

Effect of Line Resistance on Transmitter Current. Although the many advantages of central battery transmission warrant its adoption in most modern telephone systems, it does, nevertheless, introduce a further problem owing to the dependence of the sending efficiency of the transmitter upon the d.c. energizing current which varies with the ohmic resistance of the line. Fig. 101 shows the variation of transmitter current with change of line resistance. A Stone type of transmission bridge in conjunction with a 50 V battery is considered, and a nominal resistance of 50 Ω has been allowed for the terminal instrument. If it is assumed that, say, 60 mA is the minimum transmitter current to produce a satisfactory volume of speech output, then it is apparent that the line resistance must not exceed about 400 Ω when bridge impedance coils of 200 + 200 Ω are used. On the other hand, a limit of 600 Ω can be attained if the resistance of the elements in the

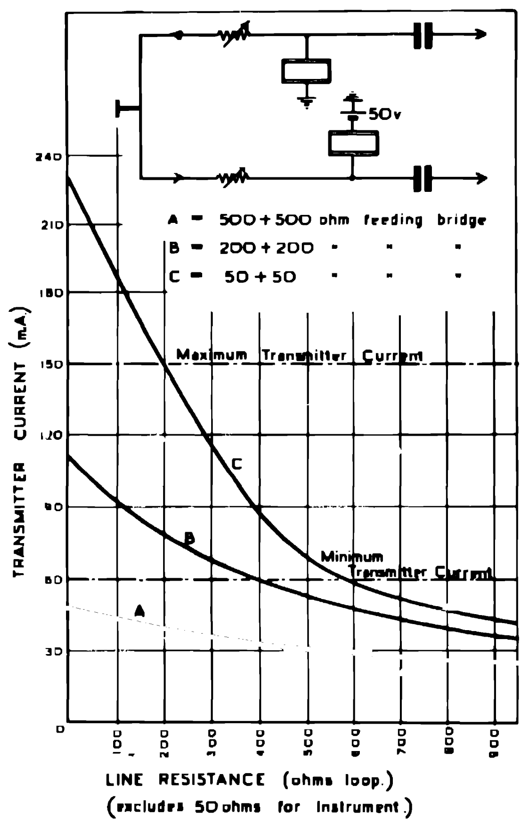


FIG. 101. EFFECT OF LINE RESISTANCE ON TRANSMITTER CURRENT

transmission bridge is reduced to 50 + 50 Ω External line plant is expensive to provide—a cost which grows rapidly as the gauge of the conductors is increased. Considerable economies can therefore be made if lines of higher resistance can be employed. There are however certain difficulties if

he increased line limits are attained by decreasing he ohmic resistance of the transmission bridge. Firstly, the bridge resistance must be sufficient to prevent excessive current on very short lines which have negligible resistance. Excessive current

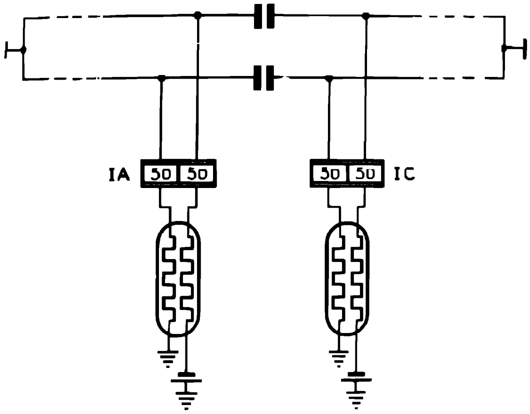


FIG. 102. TRANSMISSION BRIDGE WITH BALLAST RESISTORS

through a transmitter is even worse than insufficient current and produces severe frying and other transmitter noises, or even overheating with the consequent disintegration of the carbon granule surfaces. It is apparent from Fig. 101 that, if the maximum permissible transmitter current is, say, 150 mA, the 50 + 50 Ω bridge cannot be used when the line resistance is less than 200 Ω.

Secondly, the resistance of the impedance elements must be sufficient to prevent a burn out or fire risk if a full earth fault occurs on the *B*-line. The relay type coils usually employed have a maximum loading of about 12·5 W, and if this figure is exceeded there is the possibility of overheating and fire. In view of these considerations, the only practical value for a 50 V battery supply is the 200 + 200 Ω transmission bridge.

Apart from the direct current considerations there are difficulties in designing impedance coils of low ohmic resistance but of a sufficiently high *impedance* to prevent undue transmission losses, and the problem is still further complicated by signalling requirements which the bridge elements are required to meet. One solution would be to adjust the resistance in the feeding bridge to suit the line conditions of the telephones connected to it. In practically all telephone systems the transmission bridge is, for economic reasons, associated with common connecting circuits rather than with individual lines and hence this course is impracticable.

Ballast Resistors. In recent years a form of *ballast resistor* or *barretter* has been introduced with a view to increasing the transmitter current on long lines, but at the same time preventing excessive current on short lines. In principle, a barretter is any resistance so designed that its value varies with change of current in it and is so placed in the circuit that the change in resistance assists to maintain a uniform current. For transmission bridge purposes a ballast resistor is required which has a maximum resistance when the current is high, and a minimum value when the current is small. Ballast resistors are therefore made of a material which has a high positive temperature coefficient.

Fig. 102 shows a standard Stone transmission bridge with twin-filament ballast resistors inserted in the battery and earth supply to the impedance coils. 50 + 50 Ω coils are used, the ballast resistor giving ample protection against overheating on short lines and under fault conditions. The impedance of the coils to speech frequencies is maintained in spite of their low resistance by the provision of nickel-iron sleeves over the cores of the coils as described in Chapter VI. From a d.c. aspect, a single-filament ballast resistor in the battery lead would suffice, but this would unbalance the impedance of the two lines to earth. The unbalance varies from about 10 per cent on short lines to approximately 3 per cent on long lines and is sufficient to cause interference with transmission. It is usual therefore to divide the ballast resistance

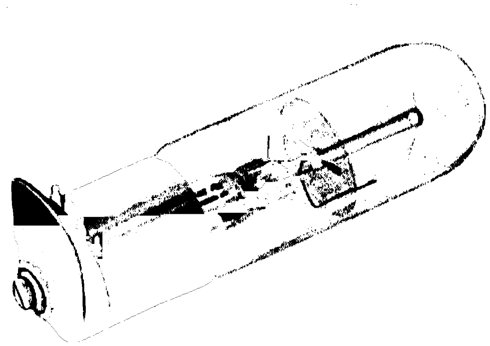


FIG. 103. TWIN FILAMENT BALLAST RESISTOR
Resistor Barretter No. 1.

between the battery and earth leads to the coil as shown, but for convenience the two separate halves of the resistor are enclosed in one glass envelope to form a twin-filament barretter.

A photograph of the standard twin-filament ballast resistor is given in Fig. 103. The two elements are of fine tungsten wire enclosed in a

hydrogen-filled bulb some 3 in. long, and the connexions are led out to soldering tags at the base; the whole unit being attached to the mounting plate by a single fixing screw.

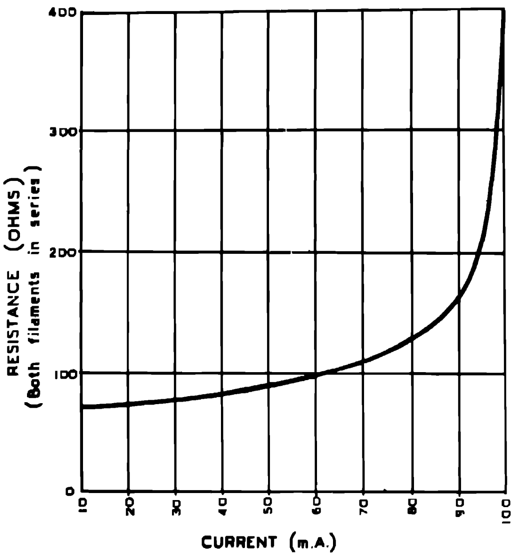


FIG. 104. RESISTANCE/CURRENT CHARACTERISTICS OF BALLAST RESISTOR

The resistance/current characteristics of an average ballast resistor are given in Fig. 104, which clearly shows the rapid increase in resistance as the current rises above about 80 mA. Great care is taken in the manufacture to ensure that both filaments are of equal resistance at all values of current. An accuracy of within 1 per cent is obtained. The filaments are raised only to dull red heat on short lines, and tests have indicated that a useful life of thirty years may be expected if there is no excessive vibration.

Fig. 105 shows the effect of the ballast resistance bridge on the value of the transmitter current for lines of different resistance. Comparing the curve of the 50 + 50 Ω coils with ballast resistor and that of the ordinary 200 + 200 Ω bridge without ballast resistors, it will be noted that for a minimum transmitter current of, say, 60 mA the maximum line resistance with the former is about 600 Ω (excluding the resistance of the telephone) as compared with about 400 Ω for the latter. Apart from the longer line limits obtainable by the use of ballast resistors there is also some improvement in the sending volume on lines of medium resistance. From Fig. 105 the transmitter current is greater when ballast resistors are used for any value of line resistance in excess of about 75 Ω. Thus if ballast resistance feeding bridges are used in an area where the line plant has been designed for non-ballast conditions there is a gain in volume which varies from about 1 db with 200 Ω lines to about 1·5 db at 450 Ω loop.

Although the ballast resistor produces a general improvement in the *volume efficiency* of a subscriber's circuit, it does not necessarily result in a corresponding gain of *articulation efficiency*. With the earlier C.B. telephone circuits, such as Fig. 83, the high value of sidetone and the bad frequency distortion prevent any material gain in articulation efficiency from the use of ballast resistors. On the other hand, with the modern A.S.T.I.C. telephone circuit (Fig. 90), the introduction of ballast resistors enables the line resistance to be increased by some 12 per cent for the same standard of articulation. The test results given at top of page 81 show the comparable line conditions for the same articulation efficiency under various conditions.

Apart from the effect of ballast resistors, these results show the very great improvements which have been made in recent years in the design of

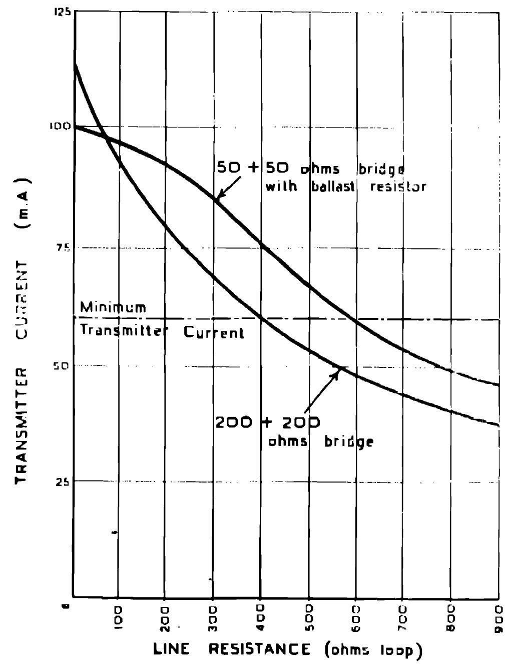


FIG. 105. TRANSMITTER CURRENT WITH AND WITHOUT BALLAST RESISTORS

telephone instruments. It will be noted that, with conductors of 6½ lb per mile, subscribers' circuits can now be routed through 2·8 miles of underground cable for the same standard of

Type of Telephone	Type of U.G. Cable (lb per mile)	50 V Ordinary Bridge (200 Ω elements)		50 V Ballast Resistor Bridge (50 Ω elements)	
		Line Resistance (ohms loop)	Miles	Line Resistance (ohms loop)	Miles
Modern A.S.T.I.C. Tele. (Fig. 90)	6½ 10 20	755 660 505	2·8 3·75 5·75	845 750 570	3·15 4·25 6·45
Early C.B. Tele. (Fig. 83)	6½ 10 20	315 175 90	1·2 1·0 1·0	320 185 105	1·2 1·05 1·2

articulation as was previously obtained over 1·2 miles of the same type of cable. With larger line conductors, the values are correspondingly greater although the gain of articulation efficiency resulting from a reduction of ohmic resistance is somewhat offset by the effect of the increased line capacitance which causes greater attenuation of the higher frequencies.

It is possible that with still further improvements in the design of transmitters, receivers, and telephone instrument circuits, the required standard of articulation efficiency, may in the future, be obtainable with line conductors of the minimum practicable size. Under these conditions there may be no economic advantage in the use of ballast resistors.

External Line Plant. Although this volume is primarily concerned with the principles and practices of signalling and switching, it is nevertheless desirable to review at this stage the electrical characteristics of the external line plant which not only affect the transmission qualities of a circuit but also determine to some considerable extent the signalling arrangements. In the early days of telephony all local lines (i.e. between the telephone instruments and the local switching point) were run overhead on poles, and largely on account of the mechanical strength required, conductors of heavy gauge were utilized. With such open wires and with conductors of up to 40 or 70 lb. per mile, not only was the total ohmic resistance of the line low, but the capacitance between wires was also small. As a result, the transmission losses in the line were low, and local lines of considerable length could be used without serious attenuation of the speech circuits. Against this, overhead lines are liable to damage by storms, etc., and the electrical behaviour of the line is appreciably affected by weather conditions. The growth of the telephone system combined with an ever-increasing congestion in towns and cities has forced local lines underground—if not completely—at least in the more congested parts of the area. Nowadays, apart from small rural areas where the telephone population is scattered over considerable distances, the local line plant consists of an elaborate system of underground cables which terminate on distribution poles or distribution boxes to serve small areas of subscribers. Underground cables and the necessary ducts, manholes, etc., are expensive to provide and in recent years considerable attention has been given to the design of cables with a view to reducing the gauge of conductors and to obtaining as many circuits as possible in a cable of given size. With modern underground planning, the speech conductors are generally either 10 lb per mile or 6½ lb per mile. As a result of this tendency towards underground line plant, the ohmic resistance of local lines is greater than before and, owing to the much greater capacitance between wires, the attenuation of speech currents is greater. Moreover, the close proximity of numerous lines in one cable demands that due precautions should be taken to avoid overhearing or disturbance between lines.

The difficulties of congestion and dependability upon weather conditions have also made it desirable that the long distance trunk lines should also be underground. Until recent years overhead construction was the only practicable means of obtaining transmission over very great distances. In a number of cases, wires of 800 lb per mile were necessary in order to give a passable standard of transmission on long trunk circuits. The advent of the electronic valve has completely revolutionized long distance transmission. By means of electronic amplifiers, underground cables of small conductor gauge can be used for long distance trunk circuits, the very high attenuation of speech currents in such cables being counterbalanced by amplifiers at regular intervals. In addition, the underground cable pairs are "loaded" by the addition of

inductance coils in the line to correct the distortion and to minimize the attenuation of speech. The introduction of amplifiers and of loading for transmission reasons also has a considerable influence upon the permissible methods of signalling.

In recent years very great strides have been made in the development of carrier systems of

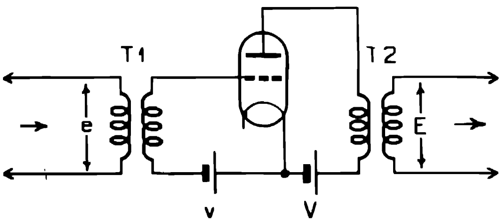


FIG. 106. PRINCIPLE OF ELECTRONIC VALVE AMPLIFIER

telephony. In these systems the initial speech is used to *modulate* or vary the amplitude of a carrier frequency and a number of different modulated carrier waves are passed together along a single physical pair of conductors. In the coaxial system, the conductor is a single wire centrally placed in a cylindrical tube, the intervening space being largely air. In this system as many as 600 conversations can be passed concurrently over the single wire. From a signalling point of view the development of carrier working and the absence of separate physical conductors for each speech channel prohibits the use of any signalling methods except those employing voice-frequency currents.

Amplifiers. The principle of the electronic valve amplifier is illustrated in Fig. 106. The incoming line is terminated on the primary of an input transformer (*T*1), the secondary of which is connected to the grid of the amplifying valve, whilst the output transformer (*T*2) is included in the anode circuit. Apart from the battery required to heat the filament of the valve, a separate potential is also required to make the static condition of the grid negative in respect to the filament, and a second battery of high voltage is included in the anode circuit to place the anode of the valve at a high positive potential in respect to the filament. Fig. 107 shows how the anode current of a simple triode valve varies as the potential applied to the grid is changed. It will be noted that when the grid volts are reduced from — 3 to zero, the anode current increases from approximately 2 to 8 mA. During this portion of the valve characteristic the change of anode current with change of grid volts is substantially linear. In an ordinary amplifier a grid potential is provided so that the normal bias on the grid of the valve is approximately half-way along the straight portion of the valve characteristic. With the curve shown, the correct bias for an amplifier is — 2 V and with this bias the normal anode current is in the order of 4 mA. If now, an alternating voltage of, say, 1 V peak is applied in series with the grid priming battery, it is apparent that, during the negative half-cycle, the maximum negative voltage on the grid increases to — 3 V, whilst at the peak of the positive half-cycle the effective bias on the grid is — 1 V. This change of effective grid voltage due to an impressed signal causes a corresponding change in the anode current. On the curve illustrated, the anode current will vary from 2 mA at the peak of the negative half-wave of the impressed voltage to 6 mA when the positive half-cycle is at its peak value. Hence, a comparatively small alternating voltage (*e*) impressed on the grid of the valve will produce a variation in the anode current, which by suitable design can be made to give a greatly amplified alternating voltage (*E*) in the secondary circuit of the output transformer. The amplifiers

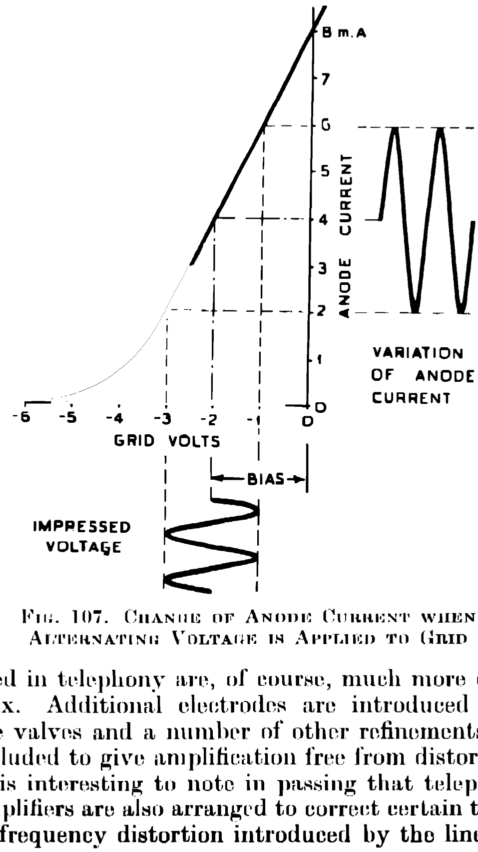


FIG. 107. CHANGE OF ANODE CURRENT WHEN ALTERNATING VOLTAGE IS APPLIED TO GRID

used in telephony are, of course, much more complex. Additional electrodes are introduced into the valves and a number of other refinements are included to give amplification free from distortion. It is interesting to note in passing that telephone amplifiers are also arranged to correct certain types of frequency distortion introduced by the line.

Two-wire Amplifiers. The basic valve amplifier is essentially unidirectional, and separate amplifiers must, therefore, be used to cater for speech in both directions on a telephone circuit. At first sight it would appear that the conditions of telephony could be met by providing two amplifiers in parallel such that one would amplify the speech in

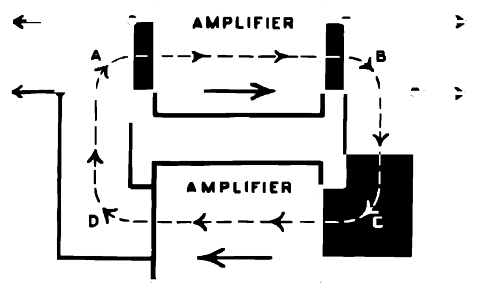


FIG. 108. CIRCULATORY CURRENTS PRODUCED BY TWO AMPLIFIERS IN PARALLEL

one direction and the second would amplify the speech in the alternative direction. On further examination it is clear that such a simple arrangement could not work. If, as in Fig. 108, two amplifiers were placed in parallel, the voltage at *A* on the input of one amplifier would be amplified to a higher voltage at *B* on the output side. With the simple parallel arrangement shown, this output voltage at *B* is also applied to the input (*C*) of the second amplifier. The voltage at *C* is now amplified to a higher voltage at *D* and this higher voltage is in turn applied to the input of the first amplifier at *A*. Hence, any signal applied to the input side of the first amplifier would be progressively amplified round and round the local circuit until such time as the losses in the circuit were equal to the total gains. This condition would only be reached when the amplifier circuits were in a state of self-oscillation. The tendency to *singing* is an important problem in telephone transmission.

Bothway amplification is in practice obtained by the introduction of balanced transformers at the points where the amplifiers and lines are linked together. Fig. 109 shows a typical arrangement. Speech transmitted from circuit *A* passes through windings *T*1 and *S*1 of transformers *T* and *S* respectively. Identical windings (*T*2 and *S*2) are connected to a local circuit which is closed by an impedance Z_A equal to that of the line *A*. The third winding of transformer *T* is connected to the input of the first amplifier, whilst the third winding of transformer *S* is connected to the output of the second amplifier. Transformers *T* and *S* are very accurately matched so that when a current passes through *T*1 and *S*1 an identical current is induced in the local circuit comprising *T*2, Z_A and *S*2. *T*1 and *T*2 are connected so that their magnetic effects are assisting to induce an e.m.f. into the third winding (*T*3). Windings *S*1 and *S*2 of transformer *S*, however, are connected so that equal currents through them in the directions shown produce no resultant magnetization and hence no voltage in the third winding *S*3. The voltage induced into *T*3 is amplified and the output is fed through winding *Q*3 of transformer *Q*. As before, line *B* is connected to windings *Q*2 and *R*2, whilst other windings (*Q*1 and *R*1) of transformers *Q* and *R* are connected to a local circuit closed by an impedance (Z_B) equal to that of line *B*. The current in *Q*3 produces equal currents in *Q*1 and *Q*2. Transformer *R* is so connected that equal currents passing through *R*1 and *R*2 magnetically neutralize and no voltage is produced in the third winding *R*3. By this means, speech from *A* to *B* is amplified, but a feed-back is avoided by the differential action of transformers *R* and *S*. Similar conditions exist when speech is transmitted from *B* to *A*. In this case, the currents in *R*1 and *R*2 magnetically assist to provide a voltage in *R*3 which is applied to the lower amplifier. The amplified current in *S*3 produces a current in *S*1 which is passed out to line *A* and a local current in *S*2. These two currents in passing through *T*1 and *T*2 are in such a direction that they magnetically neutralize each other to

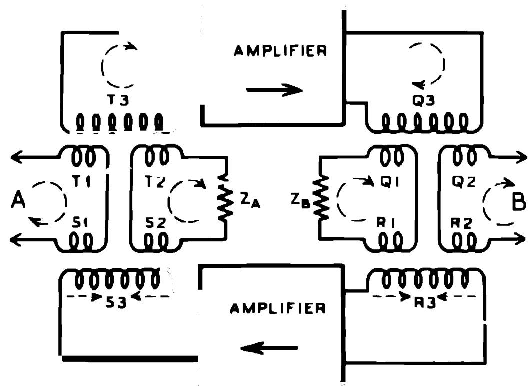


FIG. 109. USE OF BALANCED TRANSFORMERS FOR TWO-WAY AMPLIFICATION

avoid a voltage in *T*3. It is interesting to note that with this system, exactly one-half of the incoming speech energy is absorbed by the local circuit (Z_A or Z_B) and similarly one-half of the energy output is absorbed in the remaining local circuit. This loss can, of course, be made up by adjusting the gain of the amplifiers. The combinations of

transformers illustrated are known as *terminating units.* Theoretically, the impedances Z_A and Z_B should match the impedances of the relative lines accurately at all frequencies, but in practice it is found that a simple non-inductive resistance of 600 Ω is a sufficiently accurate match for most practical purposes. Both amplifiers are often mounted together to form a common unit which is known as a *two-wire amplifier* or *repeater.*

It is apparent that, when amplifiers are introduced into a transmission line, arrangements must be made to maintain the line impedance during switching operations in order that Z_A and Z_B will at all times reasonably match the line impedance. Moreover, if the two sides of an amplifier are connected together to permit the passage of signalling currents, great care must be taken to avoid "feed-back" which will produce unstable conditions.

Four-wire Amplifiers. If the local balances of the terminating units do not accurately match the impedances of the lines, then circulatory currents will occur. It is almost impossible to obtain a perfect balance at all frequencies and hence the degree of amplification introduced on a two-wire circuit is limited to the value which will maintain stability of the amplifiers. It has already been stated that stable conditions can occur only if the total losses in the local circulatory path are greater than the total gain of both amplifiers in series. This is the limiting factor on the degree of amplification at any one point on a two-wire circuit. A greater amplification per stage can be obtained by the adoption of four wires in place of the normal two speech conductors. One pair of wires carries the speech in one direction, whilst the remaining pair carries the speech in the alternate direction. The two pairs are linked together at the ends by terminating units of the type already considered. The principles of a four-wire amplified circuit are shown in Fig. 110. With this arrangement all the line losses are included in the path for any circulatory currents. Hence it is possible to adopt a high degree of amplification before the unstable condition is reached. The voltage at B is not appreciably, if at all, greater than the input voltage at the other end of the circuit (A). Any lack of balance in the terminating unit can therefore only introduce a very small voltage into the transmit pair at C, and the resultant voltage at D, is not appreciably greater than the input voltage at C due to the line losses throughout the length of the circuit. In view of the higher gain permissible per amplifier and the generally more stable behaviour of four-wire circuits, most long distance trunk lines are worked on this basis.

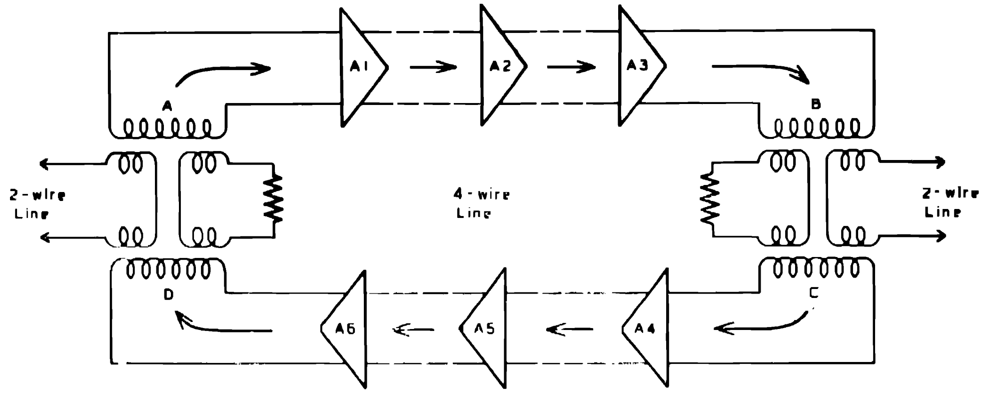


FIG. 110. FOUR-WIRE AMPLIFIED CIRCUIT

On a four-wire circuit it is possible for currents transmitted on one pair to "jump" the distant terminating unit due to out-of-balance conditions and return on the second pair to the originating telephone. This circulating current need not produce singing but may give rise to an echo effect. Means are therefore adopted on very long distance circuits to suppress this echo. A device is introduced at a convenient point on the circuit (usually at one or other terminal) which materially reduces the amplification of one pair whilst speech is being transmitted on the other pair. This device is known as an *echo suppressor* and is operated automatically by the speech currents themselves. The action of echo suppressors has an important bearing on the behaviour of voice-frequency signalling currents on a four-wire transmission system.

Loudspeaking Telephones. A possible future development is the introduction of loud speaking telephones. Such instruments cannot, of course,

meet all the requirements of commercial telephony but there is a considerable field of application in quiet offices where the user spends a large part of his time "on the telephone." The provision of loudspeaking facilities introduces a number of transmission problems. Possibly the most important difficulty is the provision of a circuit which has adequate volume and sensitivity but which will remain stable and free from self-oscillation under all conditions of use. It is apparent that an ordinary telephone circuit would not remain stable under conditions where there is good acoustic coupling between the loudspeaker and the microphone. Speech currents from the microphone induce corresponding currents in the line and part of these currents circulate through the local loudspeaker. The resultant sound energy from the loudspeaker further energizes the microphone and the currents build up until the instrument "sings" at a resonant frequency of the circuit. It has already been stated that in any reactive circuit of this type, the amplitude of self-oscillation will build up until the total losses in the circuit equal the total gains of the circuit. Thus, a sensitive microphone and the amplification of incoming speech to provide a satisfactory volume on the loudspeaker produce conditions which are diametrically opposite to those required for a stable circuit.

It would appear that the provision of a differential or balanced transformer would solve this difficulty. Such a scheme is, however, not practicable. It is comparatively easy to provide a local impedance equal to a given line impedance at a particular frequency. A satisfactory balance is impossible in practice due to the wide range of frequencies involved and the very appreciable changes of line impedance which take place during the setting up of a connexion via the public exchange. A practicable scheme has been used on internal private telephone installations by the adoption of a four-wire circuit. This principle cannot be applied to telephones which have to work over the public system where four wires from the subscriber's telephone are inadmissible on economic grounds. Moreover, even the four-wire circuit will howl unless the acoustic coupling at both ends introduces a power loss greater than the total gain of the circuit. This imposes a strict limitation on the loudspeaker volume, or alternatively it is necessary to provide a hand microtelephone at one end of the circuit to minimize the acoustic coupling.

Fig. 111 shows the arrangements of one form of loudspeaking telephone which has been developed for use on commercial two-wire circuits. In this instrument the carbon transmitter is replaced by a moving-coil microphone which, by the use of a two-stage amplifier, can be placed on the table a few feet from the speaker. Incoming speech is passed through a single stage amplifier before being applied to the loudspeaker. The loudspeaker and microphone may be mounted together or as separate units. The operation of a calling key transfers the line from a hand microtelephone to the amplifier, and at the same time calls the exchange. The ordinary telephone can be used when privacy is required.

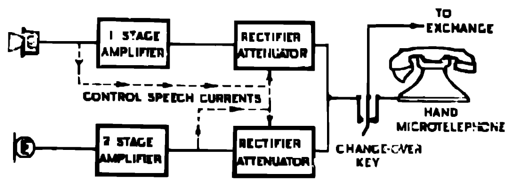


FIG. 111. GENERAL ARRANGEMENTS OF A LOUDSPEAKING TELEPHONE

A loss of approximately 30 db is normally inserted in the microphone amplifier circuit by means of a network of metal rectifiers. A similar arrangement of metal rectifiers is also placed in the receiver amplifier circuit, but the rectifiers are so biased that the network introduces a minimum loss. When the user speaks into the microphone part of the amplified speech current is rectified to produce a d.c. bias to the attenuator network. This biasing potential is so applied that the loss of the transmitting network is reduced whilst that of the receiving network is increased. Conversely, incoming speech is made to introduce the minimum loss in the receive network and the maximum loss in the transmit network. Thus, there is always a big loss in the path for the circulatory "singing" currents, the loss being transferred from the transmit to receive side of the circuit by the speech currents themselves. The switching takes only a few milliseconds and is unnoticed by the speakers. The principle is, incidentally, the same as that of the echo suppressor on long distance four-wire circuits.

Inductive Disturbances. In a telephone system, loss of speech energy during transmission can be readily made up by the introduction of amplifiers at appropriate points. Amplifiers, however, not only increase the level of the speech but also that of any extraneous noises present on the line. It is important, therefore, that the noise level shall be kept low particularly at points in the system where the speech level is low. The *signal-to-noise ratio* is in fact the limiting factor of all telephone transmission.

The main source of noise is electromagnetic (and to some extent electrostatic) induction from wires

in close proximity to the speech conductors. Fig. 112 shows a conductor *D* in close proximity to a pair of telephone wires *A* and *B*. If the current in

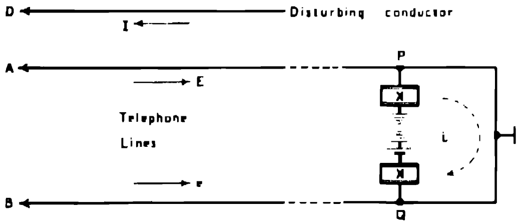


FIG. 112. NOISE DUE TO UNEQUAL LONGITUDINAL VOLTAGES

D varies in intensity, the magnetic field which embraces wires *A* and *B* also varies, thereby generating an e.m.f. in the two speech conductors. These induced e.m.f.s are in the same direction in both wires and hence are known as *longitudinal voltages* to distinguish from the *transverse voltages* (such as speech) which tend to circulate a current round the loop circuit.

If one of the speech conductors (*A*) is in closer proximity to the disturbing source (*D*) than the other conductor (*B*), then a higher voltage will be induced in the nearer conductor (*A*). Assume that the longitudinal voltages are *E* and *e*. The voltage *E* will produce a current to earth via point *P* and impedance *X* of the terminal transmission bridge. Similarly, voltage *e* on the *B*-line will produce a smaller current to earth via point *Q* and the remaining impedance element. Even if the transmission bridge elements are of identical impedance, the different current values will produce a difference of potential at points *P* and *Q*. This difference of potential, in turn, gives rise to an extraneous

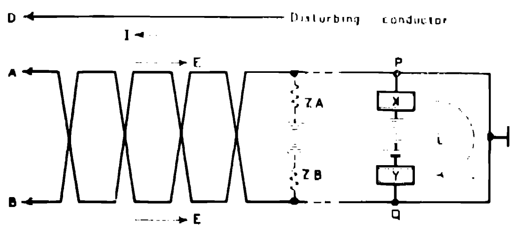


FIG. 113. NOISE DUE TO UNBALANCE OF LINE OR TERMINAL IMPEDANCES

circulatory (or transverse) current (*i*) in the terminal telephone circuit.

The conditions can be much improved by twisting or crossing the speech wires so that each conductor is at the same average distance from any outside source of disturbance (Fig. 113). By this means, the longitudinal voltages can be substantially equalized and, if the transmission bridge elements and line conductors are accurately matched, there should (theoretically) be no difference of potential at points *P* and *Q* to cause a noise current in the telephone receiver. It is, in practice, difficult to obtain transmission bridge elements which have an identical impedance to earth over a wide range of frequencies. Any out-of-balance of the impedances produces a potential difference at points *P* and *Q* and a resulting circulatory current (*i*) through the telephone instrument. Moreover, the line conductors themselves have, almost invariably, different impedances (Z_A and Z_B) to earth which result in a potential difference between *P* and *Q* even when the terminal equipment is accurately balanced.

Noise-eliminating Equipment. Inductive disturbance is often troublesome on long overhead

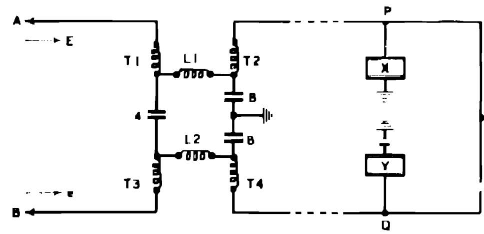


FIG. 114. THEORETICAL NOISE-ELIMINATING CIRCUIT

telephone circuits especially when the lines run in close proximity and parallel to high voltage power lines. The disturbance can be minimized by ensuring that an adequate number of crosses are introduced on the line conductors in the vicinity of the disturbance, and by maintaining a uniform standard of line insulation resistance. The use of well-balanced terminations is also an important factor in noise elimination. If, in spite of the above precautions, the noise is still excessive, special noise-eliminating equipment is introduced. Fig. 114 shows the basic elements of a modern noise-eliminating circuit. The terminal equipment is isolated from the line by a transformer *T*, the windings of which (*T*1, *T*2, *T*3, and *T*4) are magnetically assisting for circulatory speech currents. The primary speech path is closed by the 4 μF condenser whilst the secondary circuit of the transformer is completed by the two 8 μF condensers in series. Equal longitudinal currents resulting from power induction traverse windings *T*1 and *T*3 in opposite directions such that their magnetic effects neutralize, and hence no e.m.f. is induced in the secondary windings. The transformer is bridged for d.c. signalling purposes by the 20 Ω windings *L*1 and *L*2 of an iron-cored choke coil. *L*1 and *L*2

are so connected that they are magnetically assisting with line currents in the same direction (i.e. longitudinal currents) and the inductance of each winding is adjusted so that a low-pass filter is produced by the choke windings and the 8 μF condensers to earth. The inductance of each winding of L is in the order of 1·4 H, which, with the 8 μF condenser, produces resonance at about 300 c/s.

The above basic circuit is dependent upon a very accurate balance of the two 8 μF condensers. If the balance is not accurate then an e.m.f. is injected into the secondary circuit due to the passage of the longitudinal currents to earth. Fig. 115 shows a development of the basic circuit to avoid the use of very accurately balanced filter condensers. In this circuit the earthed 8 μF condensers are isolated from the secondary circuit of the line transformer by a two-winding choke M. The windings $M1$ and $M2$ are so connected that they are magnetically additive for loop currents, but introduce a negligible inductance to parallel or longitudinal currents. The speech circuit through $T2$ and $T4$ is completed by the 4 μF condenser which, in conjunction with windings $M1$ and $M2$, forms a filter circuit to smooth out any unequal voltages developed across the 8 μF condensers. It will be noted that in the final circuit the 4 μF condenser in series with the line winding of the transformer has been omitted. Windings $L1$ and $L2$ are magnetically opposing for

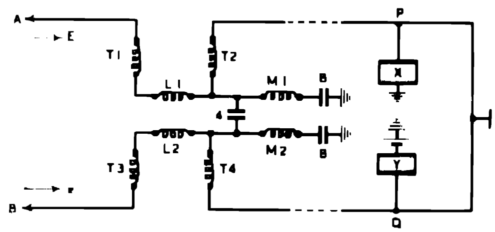


FIG. 115. PRACTICAL NOISE-ELIMINATING CIRCUIT

loop currents and hence they introduce negligible additional impedance to the speech path via the remaining 4 μF condenser.

The loss introduced by the complete filter unit is something less than 0·5 db, and the additional ohmic resistance of each wire of the junction is 20 Ω for each noise-eliminating equipment.

EXERCISES V

1. Draw a simple circuit diagram of two local battery telephones, with induction coils, connected by a pair of wires. Describe the transformations of energy that occur between the arrival of a sound wave in front of the transmitter of one of the telephones and the reproduction of the sound wave by the receiver at the other telephone. (*C. & G. Telephony, Grade I*, 1942.)

2. Explain the principle of impedance matching. A telephone transmitter of 50 Ω resistance is to be connected to a non-reactive line of 500 Ω. What must be the turn ratio of the coupling transformer to give the maximum speech energy in the line?

3. Why is an induction coil provided in a telephone instrument circuit? Why are three-winding induction coils now commonly used in local battery telephones?

4. What is sidetone and how does it influence the transmission efficiency of a telephone instrument? Describe, with the aid of simple diagrams, how sidetone is reduced in a modern C.B. telephone circuit.

5. Discuss the general requirements for transmission bridges and sketch arrangements suitable for local lines on central battery manual and automatic exchanges. Explain the advantages of ballast resistors in the latter case. (*C. & G. Transmission and Lines, Grade I*, 1944.)

6. A 40 V central battery transmission bridge consists of four impedance coils, each of 200 Ω resistance, and two line condensers. The external line resistance is 50 Ω on the answering side and 350 Ω on the calling side, the resistance of the terminating telephones being 50 Ω in each case. (*a*) What is the steady voltage across each condenser when the telephones are in circuit, and (*b*) what would be the effect on the condensers if the 350 Ω line were suddenly disconnected? (*C. & G. Telephony, Grade I*, 1945.)

7. Describe, with the aid of a block diagram, the general arrangements of one type of loudspeaking telephone.

8. Show how sidetone is reduced and acoustic shocks are avoided in the design of an operator's telephone circuit.

9. There is a severe hum on a certain junction due to the proximity of a high voltage power line. Explain how the disturbance is produced and what measures can be taken to minimize the noise. Illustrate your answer with suitable sketches.

10. Describe how a thermionic valve may be used to obtain unidirectional amplification of speech currents.

How may bothway amplification be obtained? (*C. & G. Transmission and Lines, Grade I*, 1940.)

CHAPTER VI

THE PRINCIPLES OF RELAY DESIGN

Before commencing a description of the signalling methods of telephony, it is desirable to examine in detail the design and performance of telephone relays and indicators which are the common units upon which the whole system of signalling is based. A telephone relay is any device by which a change of electrical condition in one circuit can be made to control the electrical connexions of other circuits.

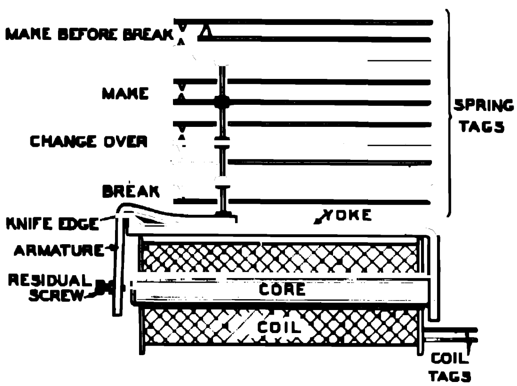


Fig. 116. General Design of a Telephone Type Relay

Until some twenty years ago the comparatively straightforward manual switching systems required relays of simple design and elementary performance, but since the advent of automatic telephony, relays have been called upon to meet the most exacting conditions of timing, sensitivity, and load capacity. Apart from the electrical performance of relays, the vastly increased number in use to-day has made it necessary to pay particular attention to the design in order to minimize fault liability and maintenance costs. Telephone indicators are based upon the same general principles as relays, but their main purpose is to give a visual indication of the receipt of an electrical signal. In addition to the visual signalling mechanism, an indicator may also be fitted with local contacts to control a subsidiary circuit. Generally speaking, however, indicators are not required to perform under the exacting conditions often imposed upon relays.

Theoretically any one of the effects of an electric potential or current may be used in the design of a relay. In practice, apart from a very limited application of the thermal principle, most relays are of the *electromagnetic type* with a fixed coil and a movable iron armature.

Telephone Type Relay. The basic features of a typical telephone relay are indicated in Fig. 116. Fundamentally the relay consists of a soft-iron *core* over which is wound a *coil* consisting of many turns of insulated copper wire. The magnetic circuit of the core is extended by means of an L-shaped *yoke* and the circuit is completed by a movable *armature* which is hinged or pivoted at the fore end of the yoke. It is usual to provide a non-ferrous *residual stud* or screw in the armature to prevent the complete closure of the iron path. The contact springs of the circuits to be controlled are fixed to the yoke, and the armature is so arranged that the *moving* or *lever springs* are lifted via pins when the relay is energized. There are numerous combinations of contacts which can be fitted to a relay, but the four types shown in Fig. 116 meet most requirements. Apart from the basic components illustrated, relays have certain additional features to improve performance or to facilitate maintenance. These characteristics are described later. It is desirable, however, that the general electromagnetic laws which govern the design and performance of relays should be summarized at this stage.

Magnetomotive Force. In any electrical circuit the current (or flow of electrons) is dependent upon the presence of an electromotive force (e.m.f.) in the circuit. In a somewhat similar manner the flux in an electromagnetic circuit depends upon the presence of a *magnetomotive force* (m.m.f.). The magnetomotive force is, of course, produced by the electric current flowing in the turns of the winding associated with the magnetic circuit. It can be shown that the magnetomotive force (F) of any current carrying coil is:

$$\text{M.M.F. (Gilberts)} = F = 4\pi NI/10 \text{ or } 1{\cdot}257NI \quad (1)$$

where I = current in amperes

and N = number of turns

In an electrical circuit, the e.m.f. is measured by the work done in moving a unit quantity of electricity round the circuit. Similarly, the magnetomotive force of a magnetic circuit is measured by the work done in moving a unit magnetic pole once round the circuit. The c.g.s. unit of magnetomotive force is the *Gilbert* and a m.m.f. of one Gilbert is such that 1 erg of work is done in moving a unit pole round the magnetic circuit. It will be noted that the magnetomotive force is determined

wholly by the value of the current and by the number of turns on the energizing coil. It is completely independent of the dimensions of the coil or the shape and material of the magnetic circuit. For some practical purposes it is convenient to express the magnetomotive force in *ampere-turns* and it is clear from equation (1) that the magnetomotive force in ampere-turns is equivalent to $1/1{\cdot}257 = 0{\cdot}8$ Gilberts (approx.).

In a series electric circuit the sum of the potential differences across each of the components of the circuit is equal to the total e.m.f. in the circuit (Kirchhoff's Law). In the series magnetic circuit, the sum of the m.m.f.'s (or magnetic p.d.'s) across the various components of the circuit is equal to the total m.m.f. for the circuit. This is very important in the solution of magnetic circuit problems.

If a current flows in a conductor, the potential drop per cm of length is determined by the value of the current, the dimensions of the conductor and the resistivity of the material. As will be seen later, somewhat analogous conditions exist in the magnetic circuit and it is often useful to know the magnetic fall of potential, i.e. the m.m.f. per cm of the magnetic circuit. Thus the *m.m.f. gradient* along a piece of material which forms part of a magnetic circuit is given by:

$$\text{M.M.F. gradient} = H = F/l \text{ (Gilberts/cm)} \quad (2)$$

where F = m.m.f. across the part (Gilberts)
l = length of part (cm)

This m.m.f., it should be noted, is not necessarily the total m.m.f. of the circuit but may be only that portion of the total m.m.f. which is required to produce the necessary flux through the part in question. (It is analogous to the p.d. across a length of wire which forms part of an electric circuit.) If the magnetic circuit is composed entirely of one material of constant cross sectional area, then the magnetic gradient is the same all round the circuit and is given by:

$$\text{M.M.F. gradient} = H = \frac{\text{total m.m.f.}}{\text{total length}} = \frac{1{\cdot}257NI}{l} \quad (3)$$

This condition does not often occur in practice (an exception is the core of a transformer without an air gap) and a value for H obtained by equation (3) must be used with caution. In most cases a magnetic circuit consists of two or more parts (e.g. an air and an iron path) and the potential gradient along each of the parts may be different (the value of H from equation (3) would give the *average* value for the circuit).

The magnetic gradient (H) is often described as the *magnetizing force* since it is this factor which determines the flux produced in a material of given constants. There is sometimes a tendency to confuse "magnetizing force" with "magnetomotive force" and it is generally preferable to use the term "m.m.f. gradient," which gives a more accurate picture of the conditions, i.e. the magnetic potential drop per cm of the circuit.

Permeability. The reluctance (or magnetic resistance) of a magnetic circuit depends upon the physical dimensions of the flux path and upon the *permeability* (or magnetic conductivity) of the material. The permeability of free space is taken as unity and all so-called non-magnetic materials have a permeability substantially equal to that of free space. Certain materials, such as iron, nickel, cobalt, etc., when placed in a magnetic field, produce a supplementary field of their own which augments the initial field. The net result is that the apparent conductivity (or permeability) of the material is very much greater than that of a non-magnetic material of the same dimensions. In the electric circuit, the conductivity of a material could be defined as:

$$\text{Conductivity} = \frac{\text{current per sq cm of c.s.a.}}{\text{potential drop per cm of length}}$$

$$\text{i.e. conductivity (Mhos) per cm cube} = \frac{I/A}{E/l}.$$

The permeability of a magnetic material is comparable with the conductivity of an electrical material. Thus, permeability can be defined as:

$$\text{Permeability} = \frac{\text{flux produced per sq cm of c.s.a.}}{\text{m.m.f. per cm length of material}}$$

$$\text{or,} \quad \mu = \frac{\phi/A}{F/l} = \frac{B}{H} \quad . \quad . \quad . \quad . \quad (4)$$

where μ = Permeability
ϕ = flux (lines per sq cm or *Maxwells*)
B = flux density (Maxwells per sq cm or *Gauss*)
F = m.m.f. (Gilberts)
H = m.m.f. gradient (Gilberts per cm.)

It has been seen (p. 49) that the electrical conductivity of certain materials (such as silicon-carbide compounds) varies with the value of the e.m.f. applied to the material. In a somewhat similar way the permeability of a magnetic material depends upon the value of the magnetizing force applied to it. The continuous line of Fig. 117 shows a typical *magnetization curve* for a specimen of soft iron. In this curve the flux density in the material is plotted against the magnetic gradient or magnetizing force. In accordance with equation (4), the ratio B/H gives the permeability at any

particular value of m.m.f. gradient. The broken line of Fig. 117 shows the *permeability* plotted against m.m.f. gradient and illustrates the very great change of permeability as the m.m.f. gradient is altered.

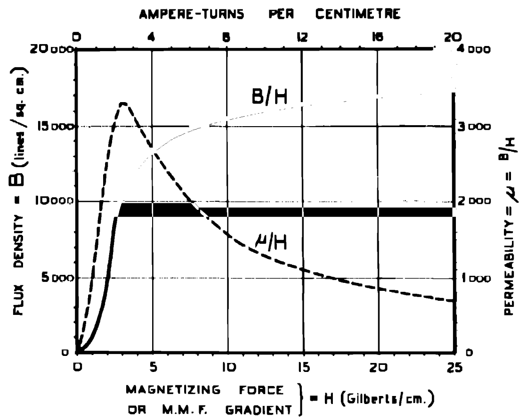


FIG. 117. MAGNETIZATION AND PERMEABILITY CURVES FOR A TYPICAL SPECIMEN OF SOFT IRON

In actual practice, magnetization (B/H) curves are produced from samples of the material to be used in a magnetic circuit. In order that the correct permeability of the material can be determined for the particular circumstances in which it will be used, it is clear that either the required flux density in the material, or the magnetic gradient along the material, should be known. If one of these factors is available, then the remaining factor can be obtained from the appropriate magnetization curve and the permeability evaluated from the two.

Reluctance. The *reluctance* of any part of a magnetic circuit depends upon the length and cross sectional area of the flux path and upon the permeability of the material, i.e.

$$\text{Reluctance} = \frac{\text{length (cm)}}{\text{permeability} \times \text{c.s.a. (sq cm)}}$$

$$\text{or, } S = l/A\mu \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where S = reluctance

l = length of magnetic circuit (cm)

a = cross sectional area of magnetic circuit (sq cm)

μ = permeability of the material

If a series magnetic circuit consists of more than one type of material or if the cross sectional areas of various parts of the circuit differ, then the total reluctance of the circuit is given by the sum of the reluctances of the various parts, i.e.:

$$S = \frac{l_1}{A_1\mu_1} + \frac{l_2}{A_2\mu_2} + \frac{l_3}{A_3\mu_3} + \text{etc.} \quad . \quad . \quad . \quad (6)$$

In a telephone relay where the magnetic circuit is almost closed by an iron path of low reluctance, the air gap forms a major part of the total reluctance of the circuit. Slight changes in the armature air gap do, therefore, produce large differences in the performance of the relay.

Occasionally (as in the case of the shunt field relay) it is necessary to consider the effect of two magnetic circuits in parallel. As in the case of resistances in parallel, the total reluctance of two or more magnetic paths in parallel, is given by:

$$\frac{1}{S} = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \text{etc.} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where S = total reluctance and

S_1, S_2, etc. = reluctances of paralleled branches.

Magnetic Circuit. The current in an electric circuit can be obtained by dividing the electromotive force by the resistance of the circuit. In a similar way the flux in a magnetic circuit is given by the m.m.f. divided by the reluctance of the circuit, i.e.:

$$\text{Magnetic flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}$$

or, with the usual symbols:

$$\phi = F/S \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

This relationship holds not only for the complete circuit but also for any part of the circuit. Thus, if the flux in and the reluctance of any part of a circuit are known, it is readily possible to calculate the m.m.f. across that part of the circuit. Conversely, if the m.m.f. gradient and the length of the part are known, the flux or the reluctance can be determined if one or other of the two latter is known, i.e. for any part of a circuit

$$H \times l = \phi \times S \quad . \quad . \quad . \quad . \quad (9)$$

The flux density at any particular part of the magnetic circuit can readily be found by dividing the flux at that point by the cross sectional area of the flux path, i.e.:

$$B = \phi/A \quad . \quad . \quad . \quad . \quad (10)$$

Finally, the ampere-turns required to produce a given flux density can be calculated by finding the total m.m.f. required in the circuit and dividing by 1·257 (see eq. 1), i.e.:

$$\text{ampere-turns} = \text{total m.m.f.}/1{\cdot}257. \quad (11)$$

The above relationships enable the flux or flux density to be calculated if the number of ampere-turns, the physical dimensions of the magnetic circuit, ***and the permeability of the materials are***

known. Conversely, the number of ampere-turns can be calculated for a given required value of flux or flux density. It has been seen above that the permeability of a magnetic material is largely dependent upon the m.m.f. gradient through it, and hence it is difficult to know in advance the permeability of any portion of the magnetic circuit before the flux or the m.m.f. gradient have been evaluated.

Where the required flux density is known, it is readily possible to find the m.m.f. gradient in the material from the appropriate magnetization curve. (E.g. in Fig. 117 a m.m.f. gradient of 8 Gilberts/cm is required to produce a flux density of 15 000 lines/sq cm in the material.) Having found the m.m.f. per cm length of the material, the total m.m.f. across that part of the circuit can be found by multiplying by the length of the material. If this principle is applied to each component part of a series magnetic circuit, then the total m.m.f. required is given by the sum of the separate m.m.f.'s across the circuit components.

In other circumstances the ampere-turns of the winding and hence the total m.m.f. are known, and the value of the flux or flux density is to be calculated. If the magnetic circuit consists of several parts, each with differing magnetic characteristics, the problem becomes somewhat complex due to the difficulty of determining the appropriate permeability of each part without a knowledge either of the flux density or of the m.m.f. distribution round the circuit. Possibly the most straightforward method of solution of such problems is to choose several likely values of flux density, and from these selected values to determine from the magnetization curves the corresponding values of m.m.f. gradient. The total m.m.f. of the circuit can then be calculated and a curve can be drawn to show the relationship between the flux density and the total m.m.f. It is then possible to find the exact value of flux density which corresponds to the given m.m.f. or ampere-turns.

In problems involving two magnetic circuits in parallel, or in more complex problems where there is a series-parallel arrangement of flux paths, it is important to remember that:

(*a*) there is the same m.m.f. across each magnetic circuit in a parallel arrangement of paths;

(*b*) the flux distributes itself through parallel paths in inverse proportion to the reluctances of the paths.

Tractive Force. The tractive force of a telephone relay is determined primarily by the value of the flux density in the armature air gap. The tractive force or pull of any magnet is given by:

$$\text{Tractive Force} = B^2A/8\pi \text{ dynes} \quad . \quad . \quad . \quad (12)$$

where B = flux density in the air gap (Gauss)

A = area of magnet face (sq cm)

When the total reluctance of the magnetic circuit is S,

$$B = \phi/A = 4\pi NI/10SA \quad \text{(Equations 1, 8 and 10)}$$

$$\begin{aligned} \text{and tractive force} &= (1{\cdot}257NI/SA)^2 \times A/8\pi \text{ dynes} \\ &= 0{\cdot}06284\, N^2I^2/S^2A \text{ dynes} \\ &= 6{\cdot}4\, N^2I^2/10^5S^2A \text{ grammes} \quad (13) \end{aligned}$$

The tractive force of a relay therefore varies directly as the square of the turns and current, and inversely as the area of pole face and the square of the total reluctance of the magnetic circuit. With a relay of fixed design, the tractive force is directly proportional to the square of the current (provided that the permeability of the iron parts remains substantially constant). It is interesting to note that, since the major part of the reluctance is concentrated in the air gap, an increase of tractive force may sometimes be obtained by enlarging the area of pole face. This increase in area tends to reduce the flux density in the gap but, since the tractive force varies inversely as the *square* of the reluctance, the consequent decrease of the latter more than compensates for the increase of area. This principle is adopted in the Post Office standard relay described later

Leakage Coefficient. Unfortunately, not all of the flux generated follows the theoretical paths assumed in the above equations. A certain proportion of the flux leaks away from the proper path, particularly in the neighbourhood of the air gap where the reluctance of the leakage paths is not vastly greater than that of the air gap itself. The flux does, in fact, distribute itself in inverse proportion to the reluctance of the various paths offered to it. The effects of this leakage are catered for by the introduction of a leakage coefficient which is defined as:

$$\text{Leakage coefficient} = \frac{\text{total flux generated}}{\text{useful flux}}$$

In modern telephone relays the leakage coefficient is in the order of 1·2 to 1·5.

Fringing. There is one important correction yet to be made. It is assumed above that the flux crosses the air gap in the form of a cylinder of parallel lines equal in diameter to the core face. This is not strictly true since *fringing* or spreading of the flux occurs between the pole face and the

larger area of the armature. In detailed calculations, therefore, some allowance must be made for the fringing which increases rapidly as the air gap is lengthened. For the short air gaps of telephone relays it is often sufficient to allow for fringing by assuming that the diameter of the flux path at the air gap is equal to the diameter of the pole face plus the length of the gap.

Inductance. When a current flows through the coil of a relay, the resultant magnetic flux is closely linked with the turns of the coil. If now the current

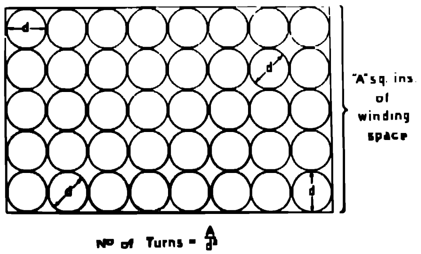


FIG. 118. NUMBER OF TURNS IN A GIVEN WINDING SPACE

changes in value, the flux cuts the turns of the winding to produce an e.m.f. which (in accordance with Lenz's Law) is in such a direction as to oppose the change of current. The value of the induced e.m.f. is determined by the rate of change of flux and by the number of turns with which it links. The electrical characteristic of a component which determines the value of induced e.m.f. for a given change of current is known as the *inductance* of the component. By definition, a circuit in which the induced e.m.f. is 1 V when the current in it changes at the rate of 1 A/sec is said to have an inductance of one *henry*.

The inductance of a relay coil can be readily calculated from a knowledge of the magnetic circuit and the number of turns on the coil. In any magnetic circuit:

The flux change when the current changes from 0 to 1 A $= 4\pi N/10S$ (eq. 1 and 8)

If this change occurs in 1 sec, the e.m.f. induced in 1 turn of the winding $= 4\pi N/10S$ electromagnetic units,

and the total e.m.f. induced in N turns $= 4\pi N^2/10^9 S$ volts

(10^8 electromagnetic units = 1 volt)

Therefore,

$$\text{the inductance} = L = 4\pi N^2/10^9 S \text{ henries} \qquad (14)$$

From the above, the inductance of a relay depends directly upon the *square* of the number of turns and inversely on the total reluctance of the magnetic circuit. With two relays of identical construction, the ratio of their inductances is the square of the ratio of their turns, i.e.

$$L_1/L_2 = (N_1/N_2)^2 \quad . \quad . \quad . \quad (15)$$

As will be seen later, the inductance of a relay determines (in conjunction with other factors) the rate of current rise when the relay is connected to a source of d.c. supply. Moreover, if an alternating potential is applied to a relay coil, the value of the inductance largely determines the resulting current by introducing an opposing e.m.f. It is interesting to note that, since the back e.m.f. is dependent upon the rate of current change, the opposition (or reactance) to alternating currents depends upon the frequency of the applied e.m.f. When the frequency is low, the rate of change of the current is also low, and the reactance of an inductance is small. On the other hand, an applied e.m.f. of higher frequency presents a more rapid rate of current change and the reactance of a given inductance is correspondingly greater.

Coil Windings. The number of ampere-turns required to give any specified tractive force can be calculated from the equations already given. Often, the approximate resistance is specified by the circuit designer and in such cases it is possible readily to calculate the number of turns required from a knowledge of the current in the circuit. (Turns = ampere-turns/current.) Having ascertained the number of turns, it is then necessary to determine the gauge of wire which will wind into the limited space of the relay coil. If, as in Fig. 118,

cross-sectional area of winding space $= A$ sq. in.
the overall diameter of wire $= d$ sq. in.
and the number of turns $= N$
then $N = A/d^2$ or $d = \sqrt{A/N}$ . . . . (16)

The above relationship holds only for the conditions shown in Fig. 118 and in practice the number of turns is somewhat greater due to the turns of one layer "bedding" between the turns of the layer below. Moreover, equation (16) is based on the overall diameter of the wire (including insulation) and hence is of limited practical value. The conditions can be met by the introduction of a *space factor* (S.F.) which may be defined:

$$\text{Space factor} = \frac{\text{total cross sectional area of conductors}}{\text{total cross sectional area of winding space}}$$

As is to be expected, the space factor varies with the diameter and the type of insulation of the wire. The factor is high for heavy gauges of wire where the insulation takes up only a small proportion of the winding space and, conversely, the space factor is lower for wires of smaller diameter. Telephone type relays wound with enamel insulated wire have a space factor ranging from about 0·5 with a 47 S.W.G. conductor to roughly 0·75 when No. 19 S.W.G. wire is used.

If d is now made the diameter of the *conductor* instead of the overall diameter of the wire, equation (16) can be re-written:

$$N = A/(d^2 \times \text{S.F.}) \text{ or } d = \sqrt{A/(N \times \text{S.F.})} \quad (17)$$

Thus, with a fully wound relay of given design, the number of turns is inversely proportional to the space factor and to the *square* of the diameter of the wire. But as the space factor itself varies with the diameter of the wire, the number of turns is inversely proportional to a slightly higher power of the diameter.

It is often desirable to know the relationship between the number of turns and the resistance of a winding.

If the average length of the turns $= l$ cm

the resistivity of the wire $= \rho$ ohms/cm³

and the total resistance of winding $=$ R ohms

then
$$\text{R} = \frac{N \times l \times \rho}{\frac{1}{4}\pi d^2} \quad (18)$$

but from (17) $N = A/(d^2 \times \text{S.F.})$

$$\therefore \quad \text{R} = \frac{A \times l \times \rho}{\frac{1}{4}\pi d^4 \times \text{S.F.}} = \frac{K_1}{d^4 \times \text{S.F}} \quad (19)$$

where K_1 = a constant for the winding.

Hence the resistance of a winding is inversely proportional to the *fourth power of the diameter of the wire* if the space factor remains constant. As before, the space factor increases as the diameter of the wire increases so that the resistance varies inversely as a somewhat greater power of the diameter.

If the value of d from equation (17) is substituted in equation (18):

$$\text{R} = \frac{N^2 \times l \times \rho \times \text{S.F.}}{\frac{1}{4}\pi \times A} = N^2 \times K_2. \quad (20)$$

where K_2 is a constant for a given winding and conductor size. The resistance of a fully wound relay coil is therefore directly proportional to the *square of the number of turns*.

It is important to appreciate that the above relationships are based on the assumption that all the available winding space is filled. If the winding space is only partly filled, then the constants are of different value depending upon the degree of fullness.

Holding and Release Conditions. Modern telephone circuits often require relays which will not only operate on a given current but which will also meet certain other conditions. Any or all of four requirements may be specified:

Operate current. This is the minimum current required to operate fully all the contact springs of the relay.

Hold current. This is the minimum current required to hold all the contact units in the operated position.

Release current. This is the maximum current which will allow the relay to release fully after it has been operated.

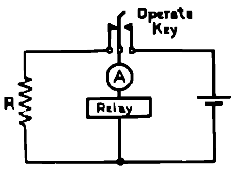
Non-operate current. This is the maximum current which can be applied to the relay without causing any of the contact units to operate.

There is sometimes an appreciable difference between the operate current and non-operate current and also between the hold current and the release current of a relay. With normal telephone relay design, there is an appreciable build-up of pressure as the armature is attracted and as the moving springs are deflected. It is therefore apparent that a current which will just not operate *any* contact unit may be appreciably less than the current required to operate fully *all* the contacts of the relay. The same conditions apply to the hold and release currents. A current of, say, 50 mA may be sufficient to hold all contact springs in the operated position, but this current may have to be reduced to, say, 40 mA in order that the armature will fully restore. Thus, in relay design calculations, allowance must be made not only for the operating condition but also for any specified non-operate, hold or release requirements.

Operate and Release Lags. In any inductive circuit, such as one containing a relay, the current does not rise immediately to its Ohm's Law value when the circuit is completed. As the current commences to rise, the increasing flux produced by the current cuts the turns of the coil and generates an e.m.f. in opposition to the applied voltage. The back e.m.f. is dependent upon the rate of change of current and, as the current rises, the b.e.m.f. decreases at a progressively lower rate. The current therefore rises in the manner illustrated in Fig. 119 until it reaches its steady value. At a specific value of current in the coil, the contact springs operate, the operate current being determined by the design and adjustment of the relay. It is clear that a time will elapse between the

moment of switching on and the instant when the current reaches the operate value. This time is known as the *operate lag* of the relay.

Similar conditions exist when the relay circuit is broken. In this case, however, the decrease in current produces an inductive e.m.f. which is in the same direction as the applied e.m.f. and, *if there is a circuit provided*, results in a prolongation of the



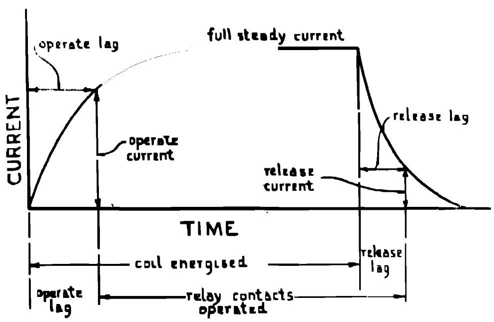


FIG. 119. RISE AND FALL OF CURRENT IN A RELAY COIL

energizing current. Here, again, there is a critical current (less than the operate current) at which the relay releases. The time delay between the moment of switching off and the actual release of the relay is known as the *release lag*. It is clear from an examination of the curve that the operate lag can be reduced to some extent by lowering the value of the operate current or by increasing the ultimate value of the circuit current. The release lag can be reduced by increasing the value of the release current or by reducing the circuit current.

The curve of current growth follows the well-known Law of Helmholtz:

$$i = (E/R)\,(1 - \varepsilon^{-(R/L)t}) \quad . \quad . \quad (21)$$

where i = the current at any instant (A)

E = applied voltage (V)

R = total resistance of the circuit (Ω)

ε = base of Naperian Logs = 2·718

L = total inductance of the circuit (H)

t = time since circuit was completed (sec).

The above equation can be written in the slightly different form:

$$i = I_m - (I_m/2{\cdot}718^{(R/L)t}).$$

where I_m = maximum current.

From the latter form it is easy to see that at a given time, say $t = 1$ sec, the instantaneous value of current depends upon the ratio R/L. If this ratio is large, then the second term of the equation is small and the instantaneous current is large. If, on the other hand, the ratio R/L is small, the second term is large and the instantaneous current is small.

The ratio R/L has a definite numerical value for any particular circuit, and if a value for t equal to the reciprocal of this value is substituted in the equation, the instantaneous current when $t = L/R$ is:

$$i = I_m - [I_m/2{\cdot}718^{\frac{R}{L}\times\frac{L}{R}}]$$

$$= I_m[1 - (1/2{\cdot}718)]$$

$$\text{or} \quad i = 0{\cdot}632\,I_m \quad . \quad . \quad . \quad . \quad (22)$$

Thus, irrespective of the values of R and L, the current at time L/R sec is always equal to 0·632 of the maximum current. The quantity L/R (reciprocal of R/L) is known as the *time constant* of the circuit and may be defined as the time that it takes the current to rise to $1 - (1/\varepsilon)$ or 0·632 of its maximum value. It is therefore possible by comparing the time constants of two circuits to visualize the relative rates of current growth. The operate lag of a relay varies directly with the time constant of the circuit, *provided that the ratio of operate current to circuit current remains constant.*

It has been shown that, other things being equal, the inductance of a relay is proportional to the square of the turns. It has also been seen that the tractive force is proportional to the square of the turns. Thus, with a relay of given resistance, the time constant increases in proportion to the tractive force required. The operate lag is therefore indirectly dependent upon the spring load of the relay.

Helmholtz's Law also applies to the release conditions, but since the induced e.m.f. now assists the current flow, the equation becomes:

$$i = (E/R)\varepsilon^{-(R/L)t} = I_m/2{\cdot}718^{(R/L)t} \quad . \quad (23)$$

In the application of Helmholtz's equation care must be taken to ensure that the values of L and R are for the *complete* circuit. This particularly applies under release conditions. It will be noted that in Fig. 119 a circuit of definite resistance (R) is applied to the relay when the energizing circuit is disconnected. In most practical circumstances the circuit is completely broken on release, and hence apart from a short period of conductivity

through the arc at the controlling contacts, the ratio L/R is infinitely small and the current quickly falls to zero. It should be noted that in Fig. 119 no account has been taken of eddy current and hysteresis effects which, as will be seen later, cause the *flux* to lag behind the current and thereby prolong the operate and release lags.

Fast Operating Relays. If a relay is required to operate with the minimum time lag it is apparent from the foregoing that:

(*a*) the ratio of operate current to circuit current should be low;

(*b*) the time constant or L/R ratio should be low; and

(*c*) the contact spring load should be light.

In addition,

(*d*) the mechanical inertia of the moving system should be small; and

(*e*) eddy currents should be reduced to a minimum.

With a relay of standard design very little can be done to reduce the mechanical inertia, but special relays with a very light moving system have been designed for use where an extremely high operating speed is required (see p. 116).

When the current rises in a relay coil, the resultant flux cuts across the solid metal parts of the relay. This flux produces an e.m.f. which in turn gives rise to eddy currents in the core, yoke, etc. In accordance with Lenz's Law, these currents are in such a direction that they oppose the change of flux which produces them. Eddy currents therefore delay the rise of flux when the relay is operating and maintain the flux on release, thereby increasing both the operate and release lags. The eddy currents can be reduced, as in an a.c. transformer, by laminating the core, yoke, and armature of a relay. This solution results in assembly difficulties and increased manufacturing costs and is not applied in practice. A considerable improvement in the performance of a relay can be made by the substitution for the normal soft-iron core of one of a nickel-iron alloy which has a high resistivity. The alloy has a 36 per cent nickel content and, although its permeability (at high values of magnetizing force) is somewhat less than that of soft iron, its resistance to eddy currents is in the order of 80 $\mu\Omega$/cm cube, i.e. about ten times that of soft iron. Nickel-iron cores are more expensive than soft iron cores and are only used when operate and release lags of 5 msec or less are required.

Slugged Relays. Use can be made of eddy-current effects to produce relays which have appreciable operating and releasing lags. Basically, all that is required is a large mass of metal of high electrical conductivity closely linked with the main flux path. Copper sleeves placed on the core under the energizing winding are effective in increasing the value of the eddy currents and have been used to some extent. By concentrating the copper at one end of the core, however, it is possible to modify the effects of the eddy currents during operation and release of the relay. In practice the mass of copper is made in the form of a cylindrical "slug" which is placed directly over the core at either the armature or the heel end. The slugs are usually of the same diameter as a fully wound spool and vary in length from ½ in. to 1½ in. depending upon the magnitude of the lag required. A slug placed at the armature end of the core makes the relay both slow to operate and slow to release, whereas the same slug fitted at the heel end of the core has little effect on the operating time but produces a full release lag. The actual value of operate or release lag depends upon a number of factors such as size of slug, ampere-turns of winding, spring load, minimum armature air gap, etc., but by the use of slugs up to 1½ in. long it is possible to obtain reliable operate lags as high as 100 msec and release lags up to about 600 msec.

Fig. 120 shows diagrammatically the effect on the operate lag of placing a slug either at the armature end or the heel end of the core. Curve (*a*) shows the normal (Helmholtz's Law) rise of flux in the air gap due to the coil alone. This flux, in growing, cuts across the copper slug in such a direction that heavy eddy currents are set up which are in the opposite direction to the current in the energizing winding. When the slug is at the armature end, a high proportion of the total eddy-current flux traverses the armature air gap. The rise and decay of this flux is shown at curve (*e*). It is in the opposite direction to the main flux and hence the resultant flux in the air gap is the algebraic sum of curves (*a*) and (*e*) and is shown by curve (*c*). The appreciable increase in operate lag will be noted.

When the slug is at the heel end of the core a considerable leakage of eddy current flux occurs between the core and the heel piece. The reverse flux in the armature air gap (curve (*d*)) is consequently less, and the effective flux (curve (*b*) = (*a*) — (*d*)) rises more rapidly than when the slug is at the armature end. It is important to realize that it is the leakage flux between the core and yoke which determines the different behaviour of relays with armature and heel end slugs.

The release conditions are illustrated in Fig. 121. During release, the eddy current flux assists the main flux and hence there is less tendency

for the flux to be diverted across the leakage paths. Leakage flux is also further reduced by the lower reluctance of the armature air gap when the relay is in the operated condition. Curve (*a*) shows the decrement of flux due to the coil alone whilst (*d*) and (*e*) show the eddy current fluxes. There is

e and *i* depict the eddy current m.m.f. and flux. The distribution of currents is, from Ohm's Law, as shown. A comparison of circuits (*a*) and (*c*) shows that the current in the "air gap" resistance is higher for the circuit representing the heel end slug. As I increases and i decreases it is apparent

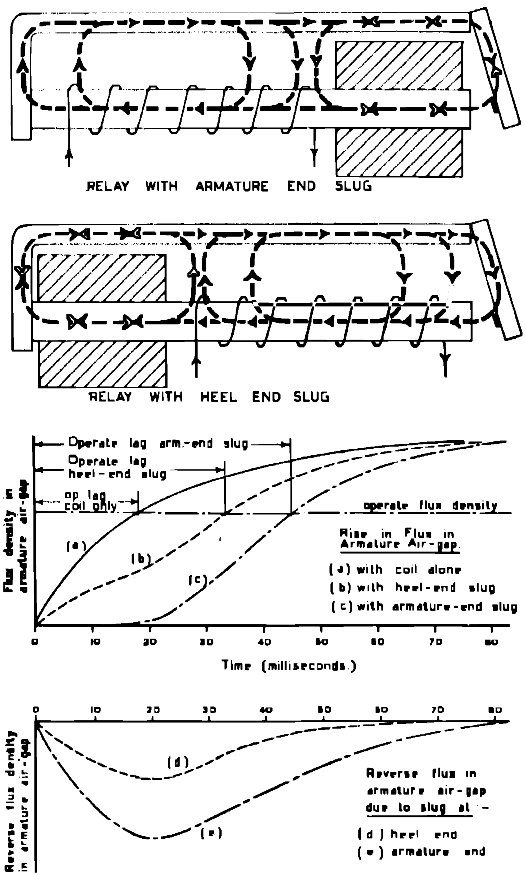


Fig. 120. Operate Conditions of Relays with Armature and Heel-end Slugs

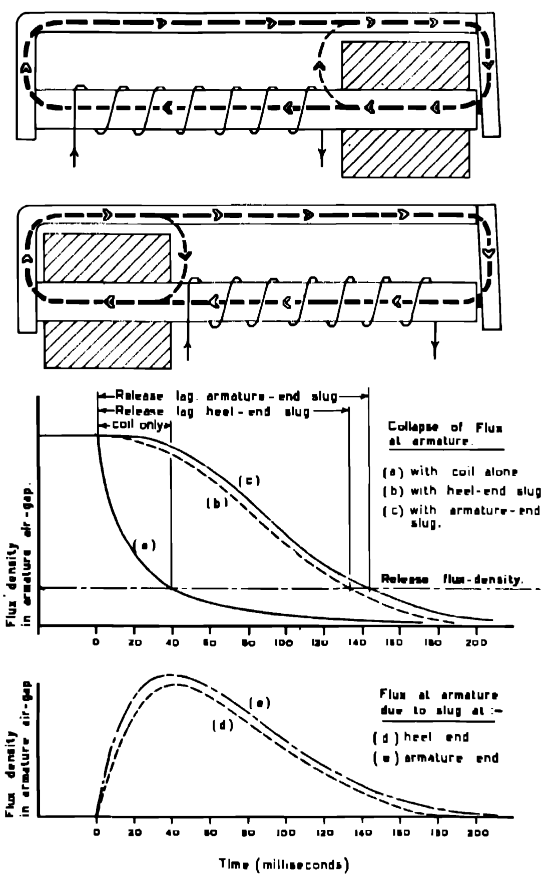


Fig. 121. Release Conditions of Relays with Armature and Heel-end Slugs

now very little difference between the curves for armature-end and heel-end slugs and hence the curves of resultant flux (*b* and *c*), and the corresponding release lags are very similar.

It is possible to illustrate the behaviour of heel end and armature end slugs by a simple analogous electrical circuit. In Fig. 122, the circuit is arranged similar to the physical components of a relay. The reluctance of the iron parts is omitted for simplicity, but the leakage paths and the armature air gap reluctances are represented by equal resistances R. Battery E and current I represent the m.m.f. and flux respectively of the energizing coil; whilst

that the current would reach a predetermined "operate"- value in circuit (*c*) quicker than in circuit (*a*).

Figs. (*b*) and (*d*) represent the release conditions of a relay, the lower armature reluctance now being indicated by a lower resistance ($R/9$ for convenience). An examination of the "air gap" currents shows that there is very little difference between the "armature-end" and "heel-end" circuits.

External Control of Timing. Apart from the methods already considered, the natural operate and release lags of a relay can be modified appreciably by its external circuit connexions. A variety

of the arrangements commonly employed are shown in Fig. 123. At (*a*) a non-inductive shunt is applied to the relay thereby providing a ready path on release for the energy stored in the coil inductance. This arrangement does not affect the operate lag of the relay but materially increases the release lag (which is of course dependent on the

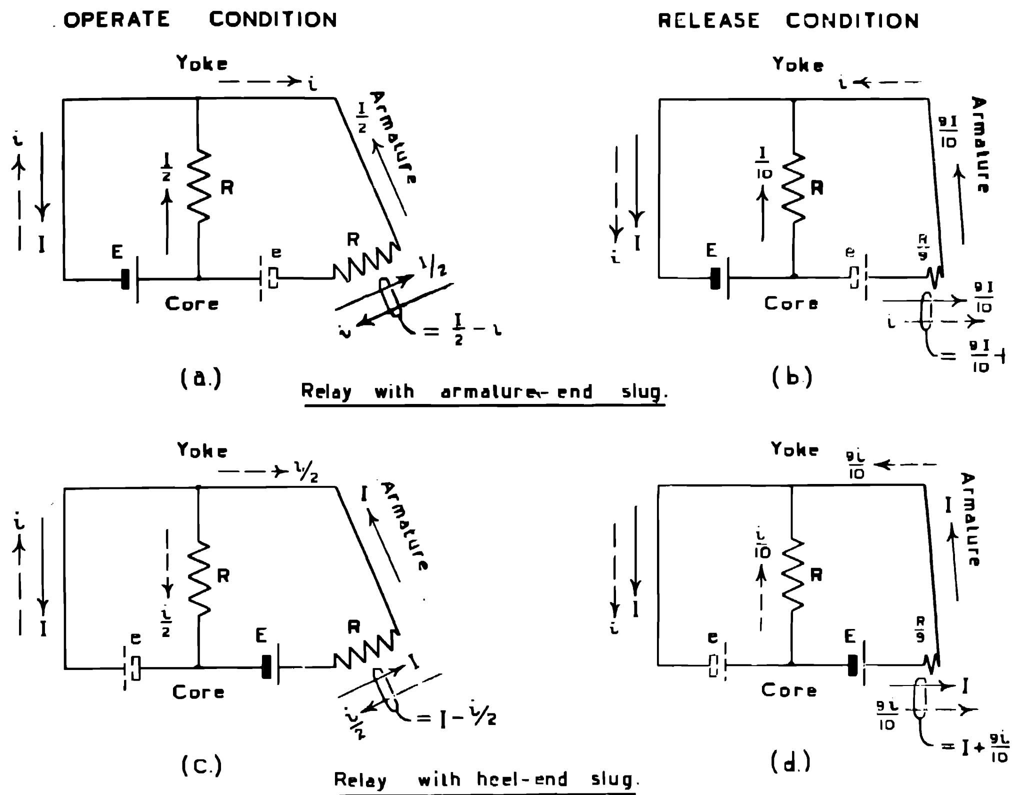


FIG. 122. ELECTRICAL ANALOGY OF RELAYS WITH ARMATURE AND HEEL-END SLUGS

L/*R* ratio of the closed circuit). The disadvantage of (*a*) is the heavy current drain. Equal or better effects can be obtained by replacing the non-inductive resistance by a metal rectifier (*b*). This prevents the wastage of current during the energization of the relay but provides a very low resistance path for the circulating currents on release.

(*c*) shows a special low resistance winding which is short-circuited when the relay operates. The second winding does not affect the operate lag but is almost equivalent to a slug during release. The same principle (*d*), in conjunction with a break contact of a relay can be used to increase the operate lag without affecting the release lag. (*e*) is a variation of (*a*) to provide a higher release lag by short-circuiting the relay coil during release. With this arrangement a protective resistance is required in the battery feed. In (*f*) the circuit is arranged to give an unnecessarily heavy current during operation in order to reduce the time taken for the current to rise to the operate value. When the relay is fully operated the 1000 Ω resistance is inserted in series to reduce the current to a more normal value. The same idea can also be used in reverse form to reduce the release lag of a relay. In this case, the current with the resistance short-circuited is normal for the operation of the relay. The insertion of the resistance when the relay is fully operated reduces the hold current to a value just above the release current, thereby reducing the release lag to a minimum.

Isthmus Armatures. Relays such as the 3000-type where the armature is mounted on a knife edge, have a high magnetic efficiency on account of the low reluctance between the yoke and the armature. This feature permits of lower operate current values but the effect on the hold and

release current values is particularly noticeable. When the armature is operated, the reluctance of the armature air gap is very much reduced and it is clear that the reluctance at the junction of the armature and yoke will have a much greater effect under these conditions than when the relay is unoperated and there is an appreciable air gap between the armature and the core face. The low

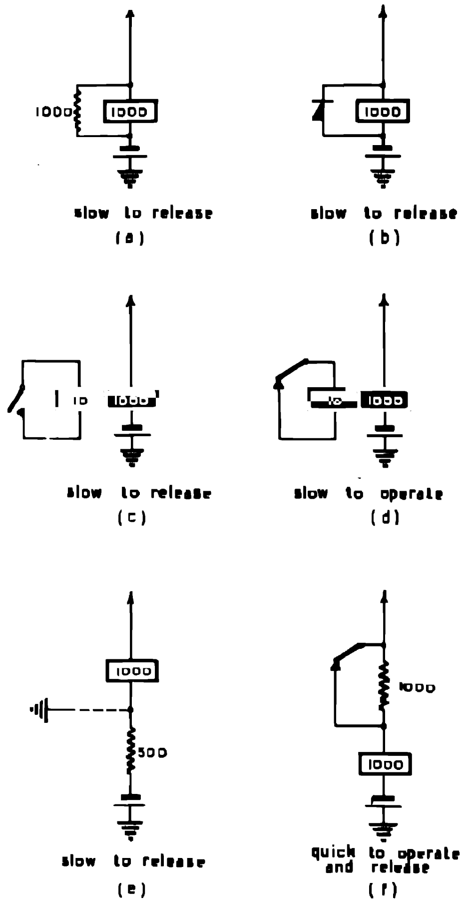


Fig. 123. Control of Operate and Release Lags by External Connexions

release current value of a knife edge type of relay is, in some circumstances, a disadvantage. If, for example, such a relay is used for impulsing, a low value of release current tends to accentuate the release lag of the relay, thereby aggravating impulse distortion.

The problems of impulsing and impulse distortion are considered in some detail in Volume II. It is sufficient at this point to note that when a knife edge type of relay is utilized as an impulse accepting relay, a special armature known as an *armature* is fitted. A common type of isthmus armature is illustrated in Fig. 124. The armature itself is of normal construction except that the iron is cut away in the portion between the knife edge and the pole face to leave a rectangular "isthmus" as the only iron path for the flux between the yoke and core. The reduction of cross-sectional area of the iron path at this point results in an increase of the reluctance of the magnetic circuit. Although the additional reluctance increases the operate current of the relay the effect is not great owing to the presence of the larger reluctance at the armature air gap. During release conditions, however, the armature air gap is of shorter length and the reluctance of the isthmus has a greater effect in limiting the value of

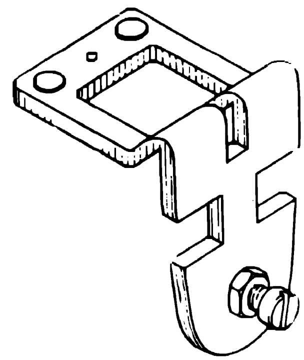


Fig. 124. Isthmus Armature

the flux. The introduction of a restriction in the magnetic circuit at the isthmus also increases the ratio of the total flux to the effective flux. This ratio is, moreover, somewhat modified by the position of the armature, i.e. whether or not it is operated. Other factors such as the variation in permeability, also enter into the performance.

The net result of fitting an isthmus armature is an increase in the ratio of the release to the operate current values of the relay.

It has been found that the shape and position of the cut away portion of the armature have an important influence on the performance of a relay and that an armature designed for one particular impulsing relay may not be entirely satisfactory on a relay of different design. Two types of isthmus armature have been standardized for use with the 3000-type relay. In one type, the isthmus is produced by parallel-sided slots cut into the armature as shown in Fig. 124, whilst in a second type the slots are V-shaped. On Siemens type relays, the isthmus effect was often obtained by providing two or three holes in the armature instead of the slots.

High-Impedance Relays. It is often necessary to design a relay which, apart from its d.c. characteristics, must offer a high impedance to alternating currents of speech frequency. To obtain a high impedance, a high value of inductive reactance at speech frequencies is necessary coupled with a low capacitance reactance. The effect of the capacitance of a relay winding is not sufficiently great at

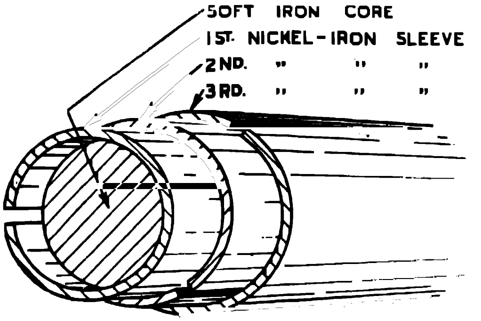


Fig. 125. Arrangement of Nickel-iron Sleeves on High Impedance Relays

speech frequencies to warrant special low capacitance windings. Some improvement can, however, be made in the a.c. inductance of the relay by the reduction of eddy currents. When speech currents pass through a relay coil, alternating eddy currents of speech frequency circulate in the solid iron core of the relay. These eddy currents, in turn, produce a flux which opposes the flux due to the primary current. The net result is a neutralization of the a.c. fluxes in the centre of the core. The action is substantially the same as the "skin effect" which is of great importance in radio-frequency work. Investigations have shown that the penetration of a.c. fluxes into the core of a relay decreases rapidly as the frequency is raised up to about 150 c/s. The depth of penetration of frequencies above 300 c/s is no more than 0·2 mm. It is apparent, therefore, that the a.c. flux resulting from a speech current in a relay coil operates entirely in a skin of the core some 10 mils thick. The a.c. inductance can be increased by employing a medium at the core surface which has a high permeability, a low eddy current loss and a low hysteresis loss. There is no material which, at the high d.c. magnetizing forces employed with relays, has a higher permeability than soft iron. The 36 per cent nickel-iron alloy used for the cores of fast relays has, however, a low hysteresis loss, a moderate permeability and a very high electrical resistance. In modern high-impedance relays, the core is of ordinary soft iron to provide the high tractive force required from the d.c. energization. Three 12 mil thick sleeves of nickel-iron are then slipped over the core to provide a medium of high specific resistance and low hysteresis loss for the a.c. fluxes (Fig. 125). The thinness of the sleeves and the longitudinal split further reduces the value of the eddy currents. The sleeves take up a small amount of winding space but this is more than compensated by the very great increase of effective impedance to speech frequencies.

Fig. 126 shows the impedance at 800 c/s of a typical 200 + 200 Ω relay with various core materials. It will be noted that although the use of a solid nickel-iron core more than doubles the impedance when there is no direct current in the windings, the impedance falls below that of a relay with an ordinary soft-iron core when the d.c. energization exceeds about 60 mA. Similarly, a

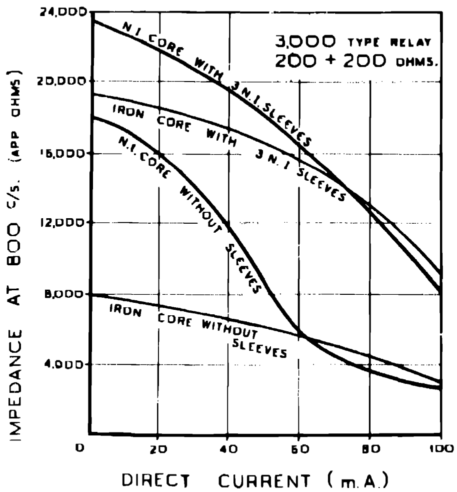


Fig. 126. Effect of Core Material on the Impedance of a Relay

solid nickel-iron core with three sleeves of the same material gives the highest impedance to speech when there is no d.c., but there is little improvement over the soft-iron core with nickel-iron sleeves for high values of direct current in the windings. These curves should be compared with the tractive force curves given in Figs. 131 and 132.

Balanced Windings. In certain cases such as, for example, the 200 Ω + 200 Ω relays used in transmission bridges, the windings must be accurately balanced as regards impedance. It is extremely difficult to obtain an accurate balance with windings one over the other or alongside each other, even though the resistances and turns are equal. To obtain a correct balance of impedance it is now usual to "sandwich" the two windings. In this arrangement, one half of the turns of one winding

are wound on the core, then the complete second winding is wound over this, and finally the second half of the first winding is put on. This gives an accurate balance of resistance, turns, and impedance.

Contact Springs. The main types of contact *unit* have already been illustrated in Fig. 116 and are shown diagrammatically in the list of graphical symbols. They are:

Make (*M*) *unit* in which a *lever spring* makes contact with a front or *make spring* when the relay is operated.

Break (*B*) *unit* in which a lever spring is disconnected from a back or *break spring* when the relay is operated.

Changeover (*C*) *unit* in which a lever spring first leaves a break spring and then connects with a make spring.

Make-before-break (*K*) *unit* in which a lever spring first makes contact with a make spring and then disconnects the make spring from the break spring.

A number of contact units assembled together in one pile are known as a *spring set*. A relay may accommodate several such spring sets.

The contact springs are invariably stamped from hard nickel-silver sheet (copper 55%, nickel 18%, zinc 27%). This material is not affected to any extent by variable climatic conditions, it maintains its tension and elasticity over a long period of use, and its tension can be readily adjusted *in situ* by stroking and bending.

Contact Materials. The surfaces at which electrical contact is made must not oxidize by atmospheric action and must retain a low contact resistance. The contact material must also withstand without deterioration the constant hammering from frequent relay operations and must have a sufficiently high melting-point to avoid disintegration due to arcing at the contacts.

An alloy of platinum (7%), gold (67%), and silver (26%) commonly known as *P.G.S.* has been extensively used as a contact material. Recent research has shown that pure silver has a less fault liability and a longer life than P.G.S., whilst the cost is approximately one-quarter of the latter. Silver contacts are therefore specified on the latest types of relay.

Silver is not suitable for heavier duties where currents greater than say 250 mA or highly inductive circuits are to be broken. In these circumstances, platinum is used in place of silver. Owing to the much higher cost (platinum is 25 times the cost of silver), the number of platinum contacts is reduced to a minimum. Springs fitted with platinum contacts are, moreover, identified by a small V-notch cut in the end of the spring.

For still heavier work tungsten contacts are necessary, particularly where currents in excess of 1·25 A are involved and where the contact hammering effect is high due to heavy contact pressures. Tungsten contacts will carry up to 5 A non-inductive, or 1 A inductive load without appreciable deterioration. Tungsten is, however, difficult to rivet to the contact springs on account of its extreme hardness, and its contact resistance is both high and erratic. A new material known as *silver-nickel* has recently been introduced and may supersede tungsten for heavy duty contacts. Silver-nickel (70% silver, 30% nickel) is not an alloy in the accepted sense of the word but consists of finely divided nickel suspended in a matrix of silver. The nickel particles give the contact material excellent wearing properties whilst the silver provides high electrical conductivity and low contact resistance. The contact resistance is in fact comparable with that of pure silver, whilst the conductivity of the material itself is about 85 per cent of the value for silver. The resistance to oxidization is very much better than tungsten. Silver-nickel contacts are capable of handling non-inductive loads up to 8 A and perform best when the contact pressure is in the order of 50 g.

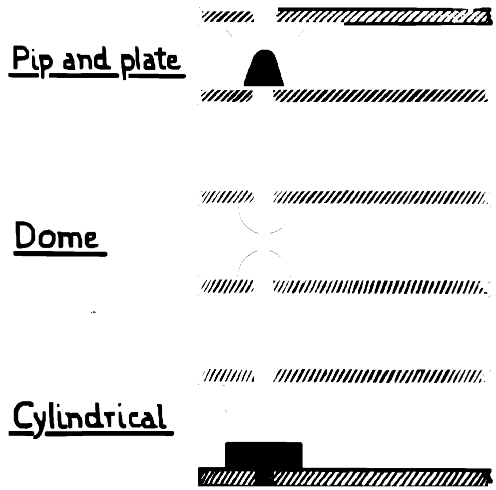


FIG. 127. TYPES OF RELAY CONTACT

On the early types of relay, the contact material of one spring was arranged as a "conical pip" whilst that of the partner spring was in the form of a flat "plate" (Fig. 127). The springs were connected in the circuit so that the current flow was from pip to plate. It was anticipated that, in accordance with the behaviour of an arc lamp, metal would be transferred from the larger pip and

deposited on the flat plate. This theory was not borne out in practice and "pip and plate" contacts have now been almost completely superseded by dome-shaped contacts of equal size. Tungsten and silver-nickel contacts are an exception and are usually in the form of short cylinders of large diameter.

Wetting of Contacts. Experience has shown that relay contacts which do not carry d.c. signalling currents tend to develop a high resistance to a.c. speech currents of small magnitude. Exposed metal surfaces are rarely chemically clean but are contaminated with substances of poor electrical conductivity. Apart from deposits of loose solid material such as dust, this contamination may take the form of extremely thin surface films (perhaps only a few molecules thick) produced by tarnish, grease, water, or even gas. Very small speech voltages are often incapable of breaking down the thin film of insulating or semi-conducting material. If, however, the voltage applied to the contacts is above a certain critical value, the film breaks down in a manner somewhat analogous to that in which a dielectric breaks down, and a metallic connexion is established through the film by metal deposited in the path of the breakdown discharge.

In modern circuit design it is the practice to apply a d.c. potential to all contacts which are required to carry speech currents only. The potential is usually obtained by shunting suitable d.c. blocking condensers with a resistance of 40 000 Ω and the process is often referred to as the *wetting* of speech contacts. The value of the "wetting" resistance is so chosen that there is an adequate p.d. to ensure breakdown of the contact film but the resulting current, after breakdown, produces only a very small p.d. at the contacts.

Twin Contacts. Investigations into the causes of contact failure have shown that a great majority of the faults are transient in nature, i.e. a particle of dust or a fine hair may lodge momentarily on the surface of a contact as the relay operates. Failures of this type can be minimized by careful attention to contact pressures and by ensuring that there is a "follow-through" after contact is made. It has been found that if the contacts are duplicated, the number of transient faults due to dirty contacts is very much reduced. It is now standard practice to provide twin contacts on all relay springs. The general design of the spring tip is shown in Fig. 128. The contact spring is split for a distance to provide the flexibility for each contact to function independently. It is important that the contacts should be adjusted to operate at the same instant to prevent uneven wear. Suggestions have been made from time to time that contact failures might be reduced by enclosing each relay in an air-tight box. Tests have been carried out with relays enclosed in glass boxes containing ordinary air, dried air, and various inert gases such as nitrogen. From these tests it was found that although there is some advantage in enclosing a complete relay group, no additional advantage accrues from the enclosure of individual relays or from the use of other atmospheres.

Contact Bounce. There is a tendency for all relay contacts to bounce at the moment of coming into contact. This bounce, if it interrupts the flow of current at the contacts, produces circuit failures which are difficult to trace and it very materially

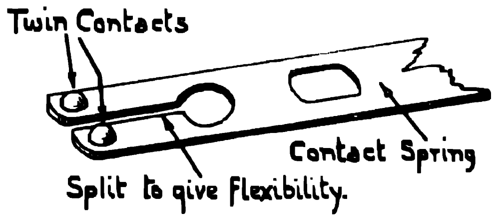


FIG. 128. CONTACT SPRING WITH TWIN CONTACTS

shortens the life of the contacts. Contact bounce can be minimized by designing the moving and fixed springs of a unit so that their natural frequencies of vibration are materially different, thereby damping any tendency for persistent vibration. This principle has been applied in some cases by the adoption of thick fixed springs in conjunction with lighter lever springs. In another relay design, the fixed springs are buffered with heavy strips which shorten the effective vibration length of the springs.

There is another form of contact bounce due to vibration of the armature during operation. During the movement of the armature, the restoring force due to the spring load does not increase steadily, but is subject to sudden changes as the lever springs engage and disengage with the fixed springs. During the same movement of the armature there is a rapid transfer of flux from the core/yoke leakage path to the armature air gap as a result of the decreasing reluctance of the latter. These two conditions produce an interaction which causes the armature to vibrate during its movement. If, for example, the armature load is suddenly increased at some point during the travel, the tractive force may be insufficient to prevent a slight reverse movement of the armature. This very small movement further reduces the available tractive force by diverting some flux through the leakage path. The vibration is, therefore, greatly increased in magnitude.

Experiments have shown that contact bounce due to armature vibration can sometimes be reduced by introducing a very small slug at the

armature end of the core. This slug usually takes the form of a copper front cheek to the relay spool which prevents the rapid swinging of flux, but does not materially increase the operate lag of the relay.

Contact Sequences. It is sometimes of great assistance to the circuit designer if certain contacts

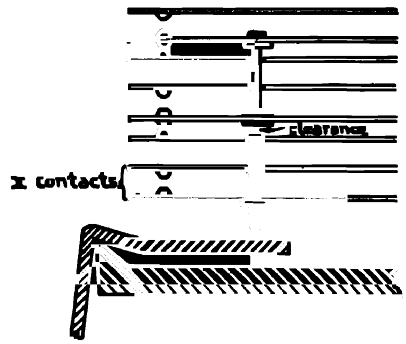


FIG. 129. "X" CONTACT ACTION

of a relay can be made to operate before or after the remaining contacts. There are two recognized sequences:

> X *contact*—a contact which operates before any of the other contacts on the relay.
>
> Y *contact*—a contact which operates subsequent to all other contact operations.

Figs. 129 and 130 show how the actions are arranged to obtain the correct sequence. It is clear that when a relay is fitted with X or Y contact

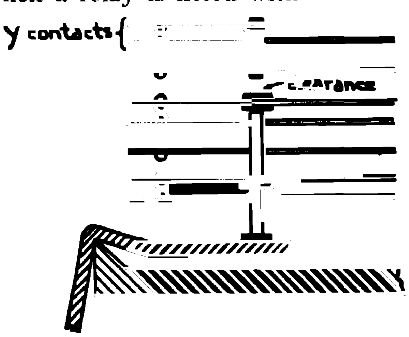


FIG. 130. "Y" CONTACT ACTION

actions the armature stroke must be greater than usual. In the past, relays have been designed where the X contacts operate at one stage in the circuit operation and the current is increased at a later stage to operate the remaining contacts. Such relays are known as *two-step relays* and are nowadays not viewed with favour on account of the critical marginal adjustments necessary.

Relay Design Practice. In practice it is not necessary to carry out detailed calculations for the selection of a suitable relay to fulfil given circuit conditions. With a relay of known design it is possible to produce standardized data in the form of graphs and tables from which the performance of a relay can be estimated. Usually the following information is prepared:

(*a*) Curves showing the relationship between the ampere-turns and the armature load.

(*b*) Tables of the load equivalents of each type of contact unit under various conditions of use.

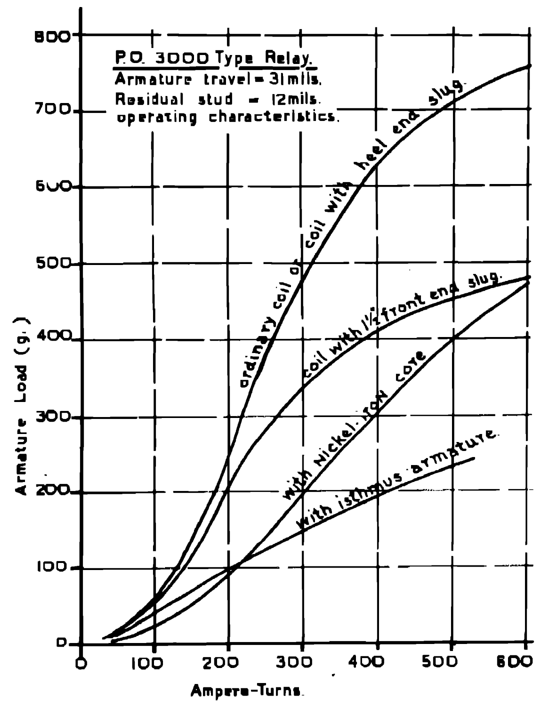


FIG. 131. OPERATING CHARACTERISTICS OF A 3000-TYPE RELAY

(*c*) The relationship between the number of turns it is possible to wind on a coil of given size and the resistance of the coil.

(*d*) Curves showing the lag obtained with each type of slugged coil under various conditions of armature load and residual value.

Load/ampere-turn Characteristics. Fig. 131 shows the ampere-turns required to operate relays with different spring loads. It is interesting to note that the introduction of a large front-end slug materially reduces (due to flux leakage) the tractive force of a relay coil. This illustration also shows the reduced tractive force of coils with nickel-iron cores and of relays fitted with isthmus armatures.

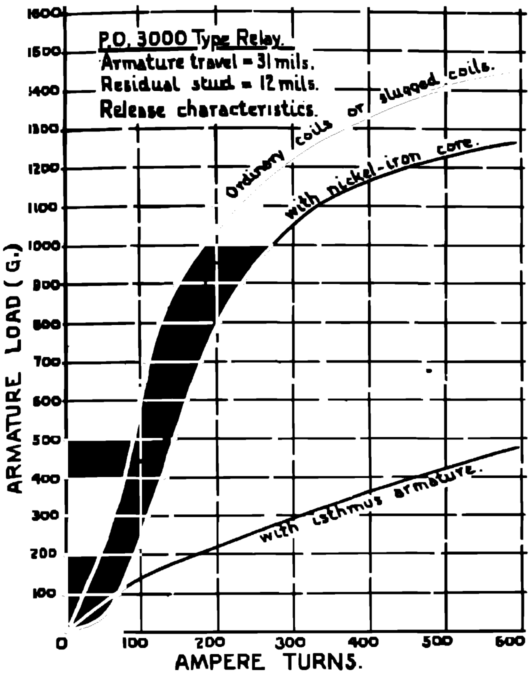


FIG. 132. RELEASE CHARACTERISTICS OF A 3000-TYPE RELAY

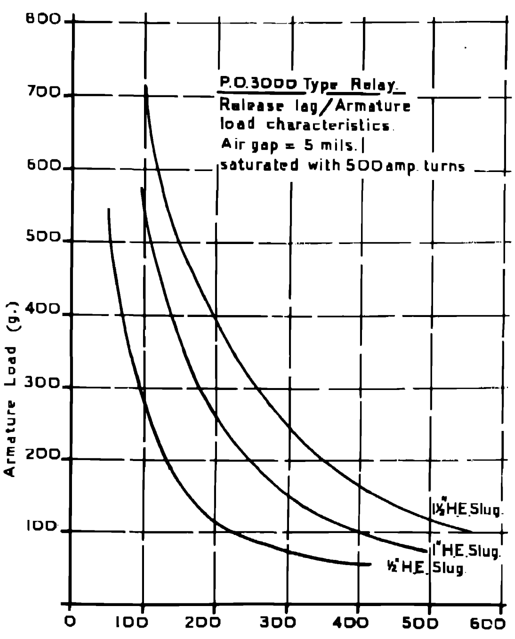


FIG. 133. EFFECT OF ARMATURE LOAD ON THE RELEASE LAG OF A RELAY

Fig. 132 gives a similar family of curves for the ampere-turns required under release conditions. The armature-end slug does not now materially affect the release load characteristics of a coil due to the lower leakage factor when the armature is operated.

Release Lag Characteristics. Fig. 133 illustrates how the release lag of a slugged relay varies with the armature load. The curves indicate that at heavy loads, a change of armature load produces only a small change in release lag. At small armature loads, however, the same change in load value

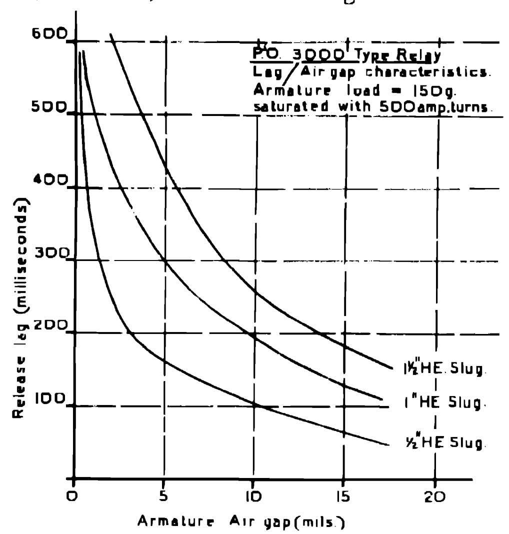


FIG. 134. EFFECT OF RESIDUAL SCREW LENGTH ON THE RELEASE LAG OF A RELAY

results in a much larger variation of release lag. To ensure uniformity of performance, it is desirable that the lag should be as constant as possible during working conditions when the spring set load may vary. It is therefore desirable whenever possible to design a relay so that it normally works on the steep part of the load/lag characteristic curve. Fig. 134 shows the effect of the residual screw length upon the release lag characteristics. The curves are of similar form to those of the previous illustration and indicate the desirability of working with the maximum possible residual screw length.

Unit Load Equivalents. The determination of the total armature load for all possible spring set combinations is not practicable. A scheme is therefore adopted in the design of the 3000-type relay in which each type of contact unit is given a *load equivalent* value. The ampere-turns required to operate, hold, etc., each type of unit are determined by experiment and the load equivalent (grammes) is read off from the appropriate

TABLE I

Typical Load Equivalents of Contact Units

3000-Type Relay

14 mil Springs, Ordinary Armature, 31 mils travel, Total of four contact units on relay

Type of Contact Unit	Residual (mils)	Unit Load Equivalent (grammes)			
		Operate	Non-Operate	Hold	Release
MAKE (M)	3 10 15	14 17 22	7 8 11	80	55
BREAK (B)	3 10 15	23 29 32	14 17 22	70	55
CHANGE-OVER (C)	3 10 15	25 30 33	14 17 22	115	90
MAKE-BEFORE-BREAK (K)	3 10 15	17 21 27	7 8 11	90	60

For 12 mil springs take 70 per cent of these load figures

load/ampere-turn graphs (Fig. 131 and 132). The load equivalents are not the actual loads measurable mechanically since the armature load during operation increases during the movement of the armature and the rate of increase is, moreover, dependent on the total number of contact units. Table I above shows typical load equivalents for the different types of contact unit. The figures relate to a relay with four contact units. These values should be increased or decreased by approximately 2½ per cent for each unit on spring sets with more or less than four contact units. To find the total load of a relay the individual load equivalents of the contact units are added together.

Factors of Safety. When the ampere-turns necessary for a given relay have been calculated from the various curves, etc., it is necessary to apply factors of safety to ensure that the product will in practice function with adequate margins. The following *working factors of safety* are therefore applied in the design of the 3000-type relay.

Operate .	. 4·0
Hold .	. 2·0 to 2·5
Release .	. 0·33
Non-operate	. 0·4

In all cases these factors represent:

$$\frac{\text{Load equivalent of circuit ampere-turns}}{\text{Nominal load equivalent of spring sets}}$$

In applying the above factors the circuit ampere-turns are calculated under the most adverse conditions of voltage and resistance.

A further factor known as the *test factor of safety* is also used to provide test current figures for the acceptance and checking of relays. It has a value of 1·75, and the test current is calculated from:

$$\text{Test current} = \frac{\text{Amp.-turns for nominal load} \times 1{\cdot}75}{\text{No. of turns}}$$

Winding Data. Winding data for relay coils is usually prepared in the form of tables which show the maximum number of turns it is possible to wind on a spool for each different gauge of wire and the resulting resistance of the winding. These are supplemented by "percentage tables" for use with partly filled spools and where two or more windings are to be accommodated on the same spool. Tables II and III give typical values for an ordinary relay spool.

TABLE II

Typical Resistance and Turn Values for a Fully Wound 3000-type Relay

Wire		Fully Wound	
Diam. (Mils)	Gauge S.W.G.	Resistance Ω	Turns
2·0	47	42 000	97 500
2·8	45	10 800	50 000
3·6	43	4 150	31 600
4·4	41	2 000	22 600
5·2	39	1 000	15 900
6·8	37	335	9 100
8·4	35	152	6 400
10·0	33	77	4 540
11·6	31	44	3 450
13·6	29	22·5	2 440
16·4	27	11·2	1 760
20·0	25	5·1	1 210
24·0	23	2·6	871
32·0	21	0·8	505
40·0	19	0·35	328

TABLE III

Percentage of Resistance and Turns for Partially Full Windings

Fullness per cent	Percentage of	
	Resistance	Turns
0	0	0
10	6·25	15·5
20	13·3	28·5
30	21·3	40·0
40	30	50·4
50	39·6	60
60	50	68·9
70	61·3	77·3
80	73·4	85·2
90	86·2	92·8
100	100	100

Example I. The use of the foregoing curves and tables can perhaps best be illustrated by a simple example. Assume that it is required to design a relay to meet the following requirements:

Contact units . . .	1M, 1C, 1B, 1K
Resistance	Approximately 1000 Ω
Residual	10 mils.
To operate	With 20 V minimum applied directly to coil.

No non-operate, hold, release or timing conditions.

From Table I, unit load equivalents of spring set

$$= 17 + 30 + 29 + 21 = 97 \text{ g}.$$

Applying the factor of safety of 4:

$$\text{Assumed load} = 97 \times 4 = 388 \text{ g}.$$

From Fig. 131, the ampere-turns required = 260. With a nominal resistance of 1000 Ω:

$$\text{Current} = 20/1000 = 0{\cdot}020 \text{ A}.$$

And hence number of turns required

$$= \frac{\text{Ampere-turns}}{\text{Current (A)}} = \frac{260}{0{\cdot}020} = 13\,000 \text{ turns}.$$

From Table II, a spool fully wound with No. 39 S.W.G. wire gives a resistance of 1000 Ω and contains 15 900 turns. A partially wound spool of a smaller gauge wire will therefore suffice.
Try No. 43 S.W.G. wire:

From Table II, turns for a fully wound spool = 31 600
but turns required = 13 000
Therefore percentage of turns = 41%
From Table III, equivalent percentage of resistance = 22% approx.
but resistance of fully wound spool = 4150 Ω
therefore resistance of partially wound spool = 22% × 4150
= 915 Ω.

If an exact value of 1000 Ω is required, a few turns of resistance wire can be added. The conditions are therefore met with a relay having the following characteristics:

Coil . .	13 000 turns of No. 43 S.W.G. wire.
Resistance .	1000 Ω

The test current of this relay for checking purposes will be the current required to operate the calculated spring load multiplied by the test factor of safety (1·75).

From Fig. 131, the ampere-turns required to operate the relay with a calculated load equivalent of 97 g are 125 approximately.

$$\text{Therefore, test ampere-turns} = 125 \times 1{\cdot}75 = 219 \text{ approx.}$$

$$\text{and no. of turns} = 13\,000$$

$$\therefore \text{Test current} = \frac{219}{13\,000} = 0{\cdot}0168 \text{ A} = 16{\cdot}8 \text{ mA}$$

EXAMPLE II. Would the relay of Example I be suitable for use in a circuit where the relay is required to "hold" with a current (after operation) of 10 mA? If not what changes can be made in the design to meet the additional requirement?

From Table I, the unit load equivalent of the spring set under hold conditions is:

$$80 + 115 + 70 + 90 = 355 \text{ g.}$$

Applying the factor of safety of 2·5,

Load equivalent of circuit ampere-turns

$$= 2{\cdot}5 \times 355 = 887 \text{ g.}$$

From Fig. 132,

$$\text{Ampere-turns required} = 145 \text{ approx.}$$

(*Note.* The same curves are used for "hold" and "release.")

$$\text{Since the number of turns} = 13\,000,$$

$$\text{Minimum safe hold current} = \frac{145 \times 1000}{13\,000} = 11{\cdot}2 \text{ mA.}$$

Hence, although the relay might in practice hold with the specified current of 10 mA a minimum of 11·2 mA is required to give the desired factor of safety.

Assuming that the residual value is to remain unaltered, the specified hold conditions can only be met by increasing the number of turns.

$$\text{Ampere-turns required to hold} = 145$$

$$\text{and minimum hold current} = 10 \text{ mA}$$

$$\therefore \text{Minimum turns required} = \frac{145}{0{\cdot}01} = 14\,500.$$

The use of 43 S.W.G. wire, as before, would give rather too high a resistance. So try 41 S.W.G. wire.

A fully wound spool gives 22 600 turns.

$$\therefore \text{percentage fullness} = \frac{14\,500}{22\,600} = 64{\cdot}2 \text{ per cent.}$$

From Table III, percentage resistance is, say, 45 per cent.

The resistance of a fully wound spool = 2000 Ω.

$$\therefore \text{Resistance for 14 500 turns} = \frac{45 \times 2000}{100} = 900\ \Omega.$$

This should be satisfactory but resistance wire can be added, as before, if an exact value of 1000 Ω is required.

The winding change necessitated by the hold condition will, of course, affect the operate current but, since the resistance remains the same, the additional turns will merely increase the ampere-turns available.

The modified relay will have the following test currents:

$$\text{Operate} = \frac{125 \times 1{\cdot}75}{14\,500} = 15{\cdot}1 \text{ mA}$$

$$\text{Hold} = \frac{70 \times 1{\cdot}75}{14\,500} = 8{\cdot}5 \text{ mA}$$

EXERCISES VI

1. A certain type of relay is to dissipate 4 W. Calculate the resistance of the winding (*a*) if the relay is to be connected between the 40 V battery terminals, (*b*) if it is to be connected in series with a resistance of 100 Ω between the same terminals. The resistance of the battery and leads is negligible. (*C. & G. Telephony, Grade I*, 1938.)

2. Calculate the approximate pull on the armature of a relay having the following characteristics:

Mean length of iron circuit . . .	30 cm
Total length of air gaps	3 mm
Number of turns on core	10 000
Mean cross-sectional area of iron circuit	0·6 sq cm
Current through coil	50 mA
Ratio B/H for the iron	600

It may be assumed for this purpose that the area of the air gap is equal to the mean cross-sectional area of the iron circuit. (*C. & G. Technical Electricity, Grade II*, 1944.)

3. What changes are caused in the time lags of a relay by the fitting of a solid copper "slug" (*a*) at the armature-end, and (*b*) at the heel-end? . . . . . (*C. & G. Telephony, Grade I*, 1945.)

4. Show how the operate and release lags of a relay can be modified by the external circuit connexions.

5. Explain how the inductance of a relay affects the growth and decay of current in the winding.

A certain relay, which has a resistance of 1000 Ω and an inductance of 10 H, will just operate when the current reaches a value of 25 mA. What time interval will elapse before the relay operates when a potential of 50 V is applied to its terminals? (*C. & G. Telephony, Grade III*, 1942.)

6. What is an isthmus armature? In what circumstances is it fitted and with what object?

7. A telephone relay has a resistance of 1000 Ω and an inductance of 25 H. The relay will just operate with a current of 16 mA and it releases when the current falls to 5 mA. Calculate the time-lags in operating and in releasing when the relay is working directly across 50-V d.c. supply terminals. Assume that the inductance remains constant, and also that, under release conditions, the relay is short-circuited. (*C. & G. Telephony, Grade III*, 1943.)

8. The core of a certain telephone relay is 6 cm in length and has a cross-sectional area of 0·7 sq cm; the yoke has an effective length of 7 cm and a cross-sectional area of 0·8 sq cm; the armature has an effective length of 1·5 cm and a cross-sectional area of 0·4 sq cm. The effective lengths of the air gaps are 0·001 cm at the heel end, 0·03 cm at the knife edge or hinge, and 0·2 cm at the armature. Calculate the total reluctance of the magnetic circuit, assuming that the B/H ratio for the iron parts is constant at 3000, and that the factor to be applied to the air gaps to correct for fringing is 0·7. Explain how the inductance of a relay is influenced by (*a*) the reluctance of the magnetic circuit and (*b*) the number of turns in the coil winding. (*C. & G. Telephony, Grade III*, 1944.)

9. State the reasons for fitting nickel-iron sleeves over the cores of certain telephone relays, and explain why such sleeves effect the desired results.

The impedance of a relay, as measured at 796 c/s (i.e. 5000 radians per sec) was increased from 7800 $\angle 50°$ ohms to 19 300 $\angle 70°$ by the use of three nickel-iron sleeves. Calculate the corresponding values of the inductance. (*C. & G. Telephony, Grade II*, 1940.)

10. Describe the constructional features which provide high magnetic efficiency and fast operation in any type of relay commonly used in automatic telephony. How does the type of contact unit (make, break, etc.) and the total spring load affect the operate lag of such a relay? (*C. & G. Telephony, Grade II*, 1945.)

11. A telephone relay of 1000 Ω resistance has an inductance of 7 H and operates with a current of 35 mA. The relay is wound with 12 000 turns of wire, and there is space for another 3000 turns. In making use of this relay in a particular circuit design, it is desired that the overall resistance between 50 V terminals shall be 1300 Ω, and this condition can be met either by connecting a resistor of 300 Ω in series with the relay, or by adding 3000 inductive turns to the winding of the relay itself. Determine which of these two arrangements should be adopted, and state the operating time of the relay, assuming that the one which will give the shorter operating time-lag is to be preferred. (*C. & G. Telephony. Grade III*, 1947.)

12. A 3000-type relay has an armature travel of 31 mils and a residual of 12 mils. It has one make, one break and two change-over contact units with 14 mil springs. The coil is fully wound and has a resistance of 1000 Ω. Allowing the usual factor of safety, calculate (from the tables and curves given in this chapter) the critical value of circuit current to ensure reliable operation of the relay.

CHAPTER VII

RELAYS, INDICATORS, AND SIMILAR APPARATUS

Early Manual Type Relays. Three examples of manual type relays of early design are given in Figs. 135 to 138. Fig. 135, which is an Ericsson design, is interesting in that it shows the influence

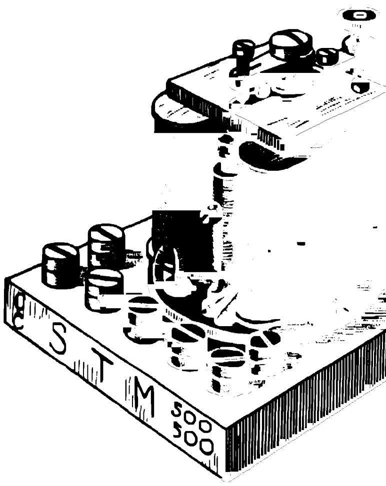


FIG. 135. EARLY TYPE OF TELEPHONE RELAY
Relay No. 1D.

of telegraph sounder principles applied to telephone switching. The relay has a large rectangular armature which is attracted to the two-coil electromagnet and provision is made for a simple changeover contact action. Fig. 136 shows a very common

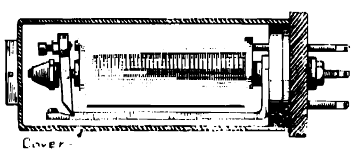


FIG. 136. KNIFE-EDGE TYPE OF MANUAL RELAY WITH COVER
Relay No. 39J.

type of manual relay in which the armature is gravity restored. This relay is very sensitive but it is not adaptable when contact units, other than a simple make action, are required. The gravity restored armature is also somewhat undesirable and the design does not provide for easy control of operate current. Nevertheless the relay is simple to adjust and is a very reliable component for use where the operating conditions are not severe

Fig. 137 shows an early General Electric Co.'s relay which provides for several contact units. The rear end of the electromagnet is extended downwards, and the armature is hinged upon it

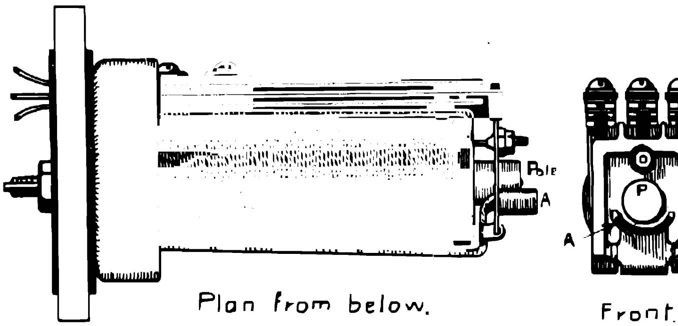


FIG. 137. EARLY MANUAL EXCHANGE RELAY WITH ARMATURE HINGED AT THE REAR

and terminates at the front in a curved surface (A) below the extended front of the core. This curved surface is covered with a thin brass sheet to prevent the formation of a closed magnetic circuit when the

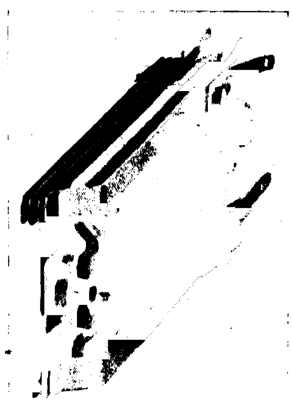


FIG. 138. FLAT TYPE RELAY

relay is operated. A light nickel-silver frame is hinged on the armature and is connected to the moving springs of the contact units above it. A conical nut enables adjustments to be made in the stroke of the armature.

A more modern manual type relay known as the *flat type* relay is illustrated in Fig. 138. This relay

was designed by Standard Telephones and Cables, Ltd., and has some advantages in respect of economy in mounting space together with ease of manufacture on mass production lines. The core of the relay, like the remaining parts, consists of a soft iron stamping of flat rectangular cross-section. The armature is U-shaped and is hinged to the heel of the core by a pair of flat steel springs. Very stiff contact springs are used on this relay in conjunction with a comparatively short armature travel. The relay suffers from a rather excessive external magnetic field which makes it necessary to position relays with care if inter-action is to be avoided.

There have been numerous other types of manual relays, and various ingenious designs for relays with special functions, but in general the arrangement illustrated in Fig. 116 has been recognized as the most satisfactory for telephone relays.

Strowger Automatic Type Relays. The relay illustrated in Fig. 139 was first introduced by The Automatic Telephone and Electric Co., and, with minor differences, was used by Standard Telephones and Cables, and Ericssons, for automatic switching circuits. The relay coil is wound on a straight core of circular section which is screwed to an L-shaped yoke of soft iron. The armature is hinged on a phosphor-bronze pin and has an extension arm (the armature lever) which operates the relay spring pile. The relay is invariably mounted so that the flat surfaces of the contact springs are in a vertical plane. Two types of armature are provided to give a 2 : 1 and a 3 : 1 ratio of spring movement to armature stroke. The 3 : 1 armature is the more common and is used for normal fast relays whilst the 2 : 1 ratio is generally employed on slow-releasing relays to reduce the effective restoring force at the armature air gap. The contact springs are fitted with single contacts and the shape of the springs is such that the armature lever can engage the moving springs directly via ebonite buffers without the necessity of introducing clearance holes in the fixed springs. This form of construction (with the off-set armature lever) facilitates adjustment and reduces the total height of the spring pile. The springs themselves are of comparatively heavy gauge and are self-positioning, i.e. they are not buffered and do not rest on any form of positioning strips or blocks. In order to allow free movement of the armature, a minimum air gap of some 1·5 mils is necessary between the armature and the yoke. This air gap

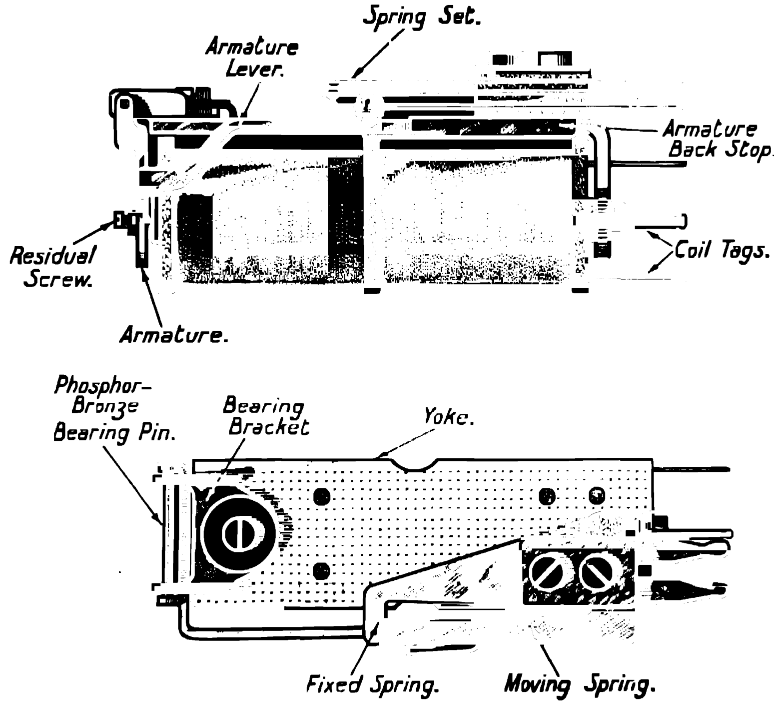


FIG. 139. STROWGER TYPE RELAY

somewhat reduces the magnetic efficiency of the relay and introduces an additional and critical adjustment feature.

During adjustment, the positioning of the fixed springs is determined by inserting feeler gauges of specified values between the armature and core face and by operating the relay electrically. The relay adjustment card specifies the size of feeler gauge which can be inserted in the armature air gap such that each particular contact just makes or breaks. Contact pressures are not specifically tested, but reasonable pressure is ensured by operate and non-operate current tests. The armature travel is also specified for each individual relay and adjustment is made by bending the armature lever. When the spring pile consists of more than one break contact, adequate pressure at each contact is obtained by specifying gauging

which determines that the contact nearest to the armature lever breaks first and the remaining contacts break in sequence. This ensures that the first break contact does not take the full pressure of the spring pile to the detriment of the remaining break contacts. Possibly the greatest merit of the Strowger type relay is the ease of adjustment of the contact springs. Against this, the system of locating the contacts by armature gauge is somewhat involved and the necessity for current tests is also a complication in practice. The spring pile of the Strowger relay cannot be detached from the yoke as a complete unit. If, therefore, it becomes necessary to change a worn contact spring, the whole spring assembly must be dismantled and a special jig is required for re-assembly.

Siemens Automatic Type Relay. The relay illustrated in Fig. 140 was designed and introduced by Siemens Bros., and was later used by the General Electric Co., Ltd. It has a number of features which have been adopted in the Post Office standard relay (3000-type). The L-shaped armature rests upon a knife-edge formed at the front extremity of the yoke. This method of mounting the armature provides a fulcrum of low frictional loss and which is substantially unaffected by wear. The large end area of the knife-edge gives a flux path of low reluctance and, provided that the armature is of the correct shape, no adjustment at this point is necessary. The core has an enlarged pole face to improve the performance of the relay and a good magnetic joint is obtained between the core and yoke. The spring sets are designed as self-contained units which are attached to the yoke by means of a single fixing screw, lateral movement being prevented by a channel-section mounting platform. All the contact springs are straight and the moving springs are operated by means of lifting pins which pass through clearance holes in the fixed springs. The contact springs are somewhat thinner than those of the Strowger relay but they are supported, where necessary, on buffer strips of very heavy gauge. During assembly the contacts springs are provided with a slight set so that when they are clamped along with the buffer strips there is a definite pressure between the two. The adjustment specification calls for a pressure between the contact spring and the buffer of from 15 to 20 g, depending upon the gauge of the spring. The contact clearance (15 to 20 mils) and the armature travel are also specified. These mechanical adjustments in conjunction with operate and non-operate current tests provide the necessary check of performance. When the relay is operated, the fixed contact springs are required to lift clear of their associated buffer strips. If this adjustment is correct then adequate pressure is assured. The buffer strips also tend to reduce contact bounce by stiffening the fixed springs. The Siemens type relay was originally designed for mounting with the spring sets uppermost but the relay is now always arranged with the spring set at the side in order to give a greater freedom from contact failures. Under these conditions displacement of the armature is prevented by a notch in the centre of the

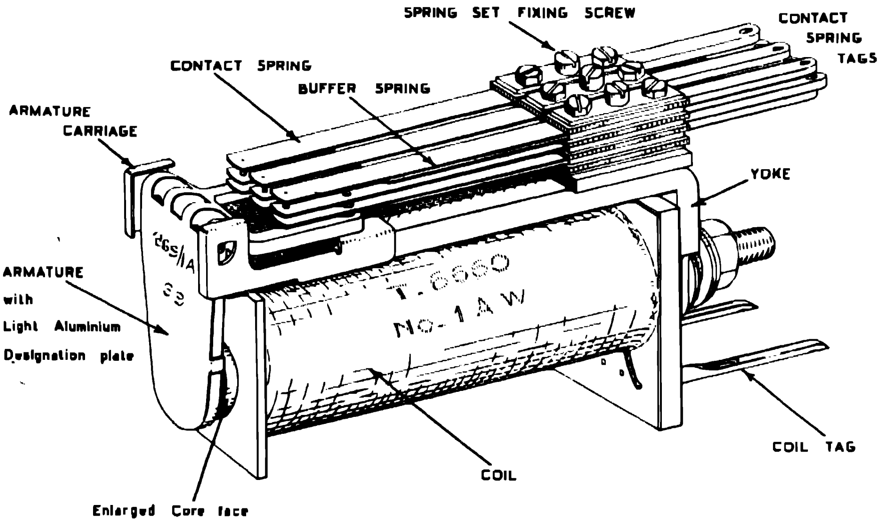
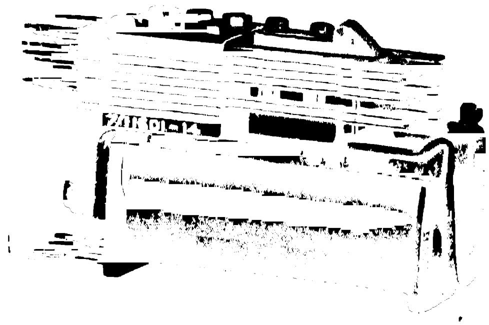
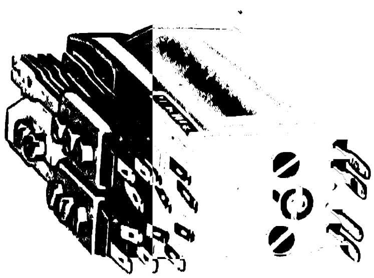


FIG. 140. SIEMENS TYPE RELAY

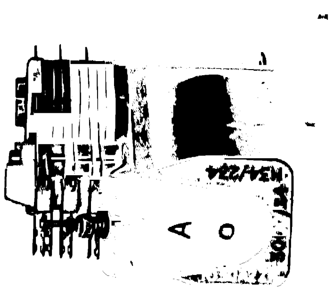
nife-edge which engages with a small pip on the side of the V-bend in the armature. In addition, the armature is prevented from lifting from the knife-edge by a light nickel-silver carriage, the side



(a)



(b)



(c)

FIG. 141. THE P.O. 3000-TYPE RELAY
(a) Plan view. (b) Rear view. (c) Front view.

plates of which embrace short brass pins riveted into the sides of the armature. This carriage forms, in effect, a loosely fitting hinge.

The magnetic circuit of the Siemens type relay is excellent and the relay has a very high performance. On the other hand, the contact springs are somewhat difficult to adjust owing to the presence of the buffer strips.

Post Office 3000-Type Relay. Until the year 1932 the various telephone equipment manufacturers provided relays of their own design to meet the overall requirements of the Post Office. This arrangement provided invaluable experience of the various features of each design and the experience was utilized as a basis for the development of a

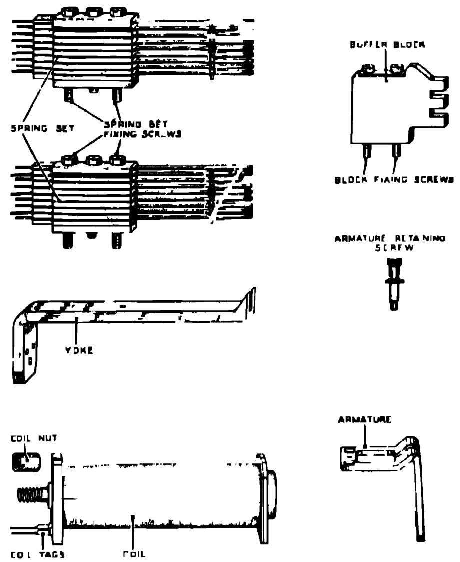


FIG. 142. COMPONENTS OF 3000-TYPE RELAY

standard Post Office telephone relay. The advantages of standardization of such a common component are obvious. It ensures uniformity of product from different manufacturers, facilitates maintenance replacements, and simplifies the training of staff, etc.

The standard relay is known as the Post Office 3000-type to correspond to the code numbering of the relays in the 3000 *et seq* series. General views of a typical relay are given in Fig. 141, whilst Fig. 142 shows the component parts. The core is of soft "Armco" iron and with its windings forms a complete sub-assembly which may be withdrawn from the relay by removing the single core nut. The core face is enlarged in order to reduce the reluctance of the air gap. The windings (which are, of course, insulated from the core) are terminated on tags fixed to the bakelite rear coil cheek and a uniform system of tag allocations is employed. Tags connected to the inner (or core) ends of the windings are marked with a red band and it is usual to connect this end of a winding to the

earth side of the circuit. Apart from the winding details there are four types of coil:

(*a*) *Plain*—for general purpose relays where the timing is not critical. Plain coils are fitted with a copper front cheek to minimize contact bounce.

(*b*) *Nickel-iron sleeved*—These coils are fitted with three 12 mil split sleeves of nickel-iron sheet (36% nickel) and are used where the maximum impedance to speech currents is required.

(*c*) *Slugged*—Coils with armature-end or heel-end slugs for use when appreciable operate or release lags are required. Three standard lengths of slugs are employed: ½ in., 1 in., and 1½ in. With the largest slug it is possible to obtain up to 100 msec operate lag, and 600 msec release lag under favourable conditions.

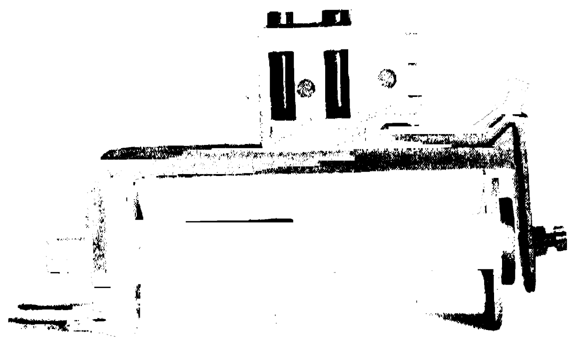


FIG. 143. SKELETON OF 3000-TYPE RELAY

(*d*) *Bakelite front cheek*. In this coil the standard copper front cheek is replaced by a bakelite cheek. It is used in circumstances where a relay must be critically fast in operation and where the slight slugging effect of the copper front cheek is undesirable.

The magnetic circuit may be seen clearly from Fig. 143 which shows a relay stripped of the winding and contact springs. All iron parts are protected against rust by nickel plating over a flash of copper. Nickel plating has the great advantage over other forms of protection that the additional reluctance introduced at the joints is a minimum. The yoke is of L-shape and has a machined knife-edge at its front extremity. A close magnetic joint is effected between the yoke and core, which are clamped together by the large cylindrical nut.

The armature is of light construction to minimize its mechanical inertia, and is fitted with either a fixed phosphor-bronze residual stud for ordinary relays or with an adjustable residual screw where fine adjustment of residual value is required to meet the circuit conditions. The armature rides on the knife-edge of the yoke, and lateral displacement is avoided by the spring-loaded fixing screw. An isthmus armature is used on impulsing or similar relays to obtain a more uniform performance and to minimize impulse distortion.

Four standard contact actions are provided: Make (M), Break (B), Change-over (C) and Make-before-break (K). The maximum capacity of the 3000-type relay is eighteen springs (i.e. nine makes or breaks or six change-overs, etc). The contact units are arranged in two piles—one on each side of the buffer block—and the loads of the two piles are adjusted to be as equal as possible. When there is only one contact unit it is placed on the left side of the buffer block. Generally speaking, the make contact units are placed nearest the armature followed by the break, change-over and finally the make-before-break units. The tags of the contact springs are staggered to facilitate wiring, with the tags of the lever springs innermost and those of the fixed springs on the outside. The springs of each pile are numbered 1, 2, 3, etc., and 21, 22, 23, etc., counting from the yoke.

In accordance with the general practice, the springs are of nickel-silver. 14 mil springs are standard but in certain cases it is necessary to resort to 12 mil springs. Exceptionally, specially stiff springs are provided to meet unusual circuit conditions. Twin dome contacts are normal and the springs are split for a distance in order to allow sufficient flexibility for each contact to function independently. The standard contact material is pure silver. For currents in excess of about 300 mA, or under conditions of heavy usage, the silver is replaced by platinum. Platinum contacts are identified by the usual notch in the end of the spring and it is a rule that when there are two or or more similar contact units on a relay, the unit with platinum contacts is placed nearest to spring 1.

Normally, sequence of contact action is regarded as undesirable, but, when the circuit conditions make a sequence necessary, arrangements are provided for one X-contact unit or one Y-contact unit (but not both on the same relay). Relays with X and Y contacts require a special buffer block and a larger armature travel.

The outstanding feature of the 3000-type relay

he white buffer block which serves as a position-piece for the contact springs (Fig. 144). The nt portion of the block is formed into series of

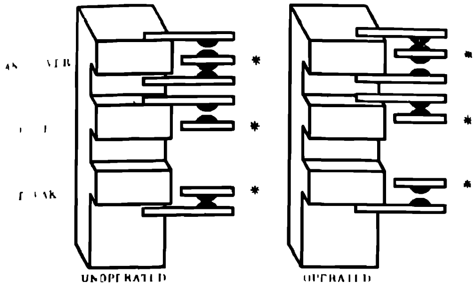


FIG. 144. BUFFER BLOCK METHOD OF SUPPORTING SPRINGS
Lever springs shown *.

steps which engage with projecting lugs on the side of the contact springs. If the springs are kept straight, the contact clearances are automatically correct. Moreover, when the springs are tensioned to the required minimum pressure against the buffer block, adequate contact pressure is assured if the relay is adjusted so that the lugs leave the block during operation. There are five standard buffer blocks in order to cater for the various contact combinations.

3000-Type Relay Adjustments. As already stated, the 3000-type relay has been designed so that the contact clearances are automatically fixed by the buffer block. Check of adjustments by means of test currents is avoided wherever possible, and maintenance is considerably simplified by the adoption of standard spring tensions and armature travel. Relays with the standard 14 mil springs, and which can be maintained by the application of the standard adjustments, are fitted with a *white label* on the front coil cheek (Fig. 145). For such relays the following are the standard adjustments:

(*a*) Armature stroke	= 29 to 33 mils.
(*b*) Residual length	= 4, 12 or 20 mil studs, or adjustable screw.
(*c*) Pressure of all buffer springs (except K units) against block	= 16 to 20 g.
(*d*) Pressure of make lever springs	= 5 to 8 g.
(*e*) Pressure of K contact against block	= 30 g minimum.

When a relay is fitted with 12 mil springs, tensions (*c*) and (*e*) are reduced to 11–15 g and 21 g minimum respectively, and the relay is given a *green label*. In both cases 1 g above and below the limits is allowed before it is necessary to readjust the

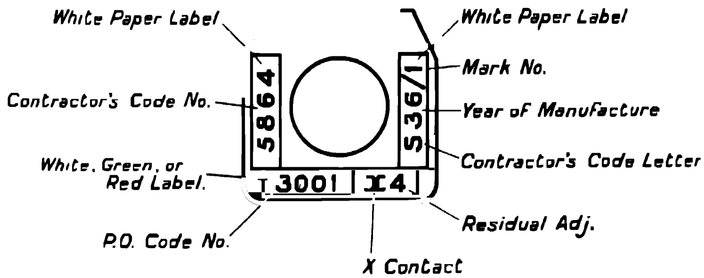


FIG. 145. LABELLING SYSTEM OF 3000-TYPE RELAY

relay. When X or Y contacts are fitted the standard armature stroke is 43 mils. (± 2 mils).

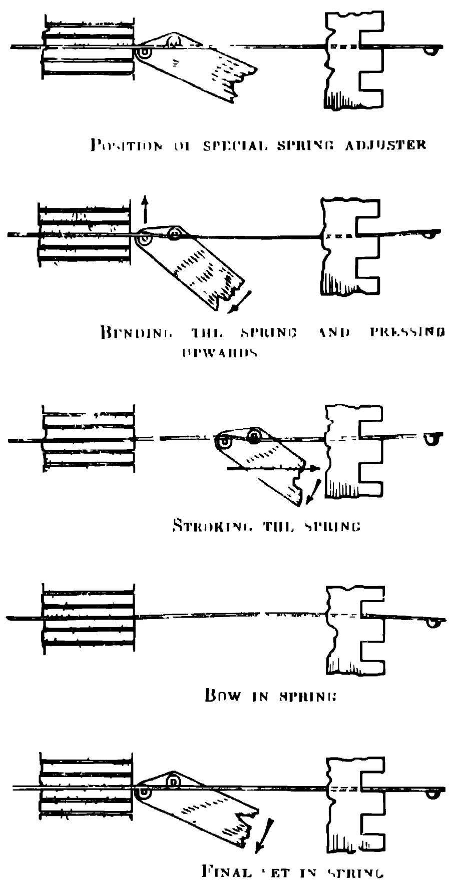


FIG. 146. METHOD OF TENSIONING A SPRING AGAINST THE BUFFER BLOCK

When it is not possible to meet the circuit conditions with a relay in standard adjustment, individual adjustments and current tests are specified on a relay adjustment card. Such relays are fitted with *red labels* to indicate that reference must be made to the appropriate card. In certain cases it is necessary to adjust the residual length of white or green label relays during manufacture to meet current or timing requirements. The manufacturer enters the most suitable residual value on the relay label so that the relay can be maintained without any further current or timing tests.

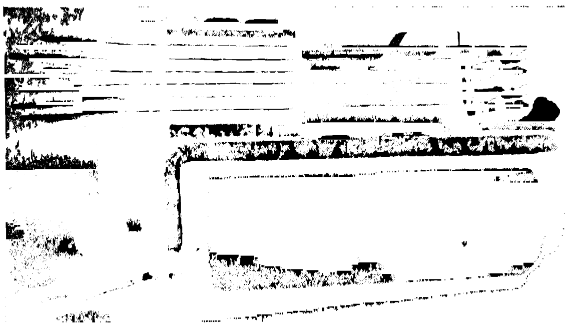


FIG. 147. P.O. 600-TYPE RELAY

The spring tensions are measured from the tip by means of a calibrated pressure gauge. If adjustment is required, a pair of duckbill pliers or a special spring adjuster are used. The procedure for increasing the tension of a spring against the buffer block is illustrated step by step in Fig. 146. The method of decreasing the tension is very similar but the tool is reversed and the pressure is applied in the opposite direction. It is important that, after adjustment, the spring is straight in order that the correct contact clearances are obtained.

The 600-Type Relay. The Post Office 600-type relay is supplementary to the 3000-type and has been designed for use in circumstances where space and cost are important and when critical performance is not required. The relay (Fig. 147) is based on the same general design as the 3000-type but is much smaller and lighter. (The weight of an average 600-type relay is about 4 oz.) The knife-edge mounting of the armature is simplified and the contact units are limited to a maximum of twelve springs with no X or Y sequences. Provision is made for one or two windings and slugged coils can be provided, but critical adjustment of operate current and operate or release lag is not envisaged. Fixed residual studs of 4, 8, or 12 mils are employed and only one gauge of spring (14 mils) is provided. Adjustable residual screws are not used and the relay is free from current tests and all special mechanical adjustments.

The 500-Type Relay. The relay illustrated in Fig. 148 and known as the Post Office 500-type was introduced as an advance type of small standard relay prior to the development of the 600-type. It has been used to a limited extent, particularly in subscribers' apparatus.

Shunt-field and Polarized Relays. A polarized relay is one in which the relay operates only when the energizing current flows through the coil in a specified direction. The *shunt-field relay* is a special form of polarized relay in which the core of the operating winding is shunted by a path of low reluctance. Under these conditions an external field in the armature air gap can only be produced by the introduction of an opposing magnetomotive force in the parallel shunt path. Basically the principle is the same whether the opposing magnetomotive force is obtained by the current in a special polarizing winding or by introducing a permanent magnet in the shunt path. It is usual, however, to reserve the term "shunt-field relay" to a relay which is electromagnetically polarized and to classify all relays with a permanent magnet as "polarized relays." Fig. 149 shows the principle of operation of the shunt field relay. Winding *AB* is the operating or line winding and *CD* is the polarizing coil. Both the line and polarizing coils

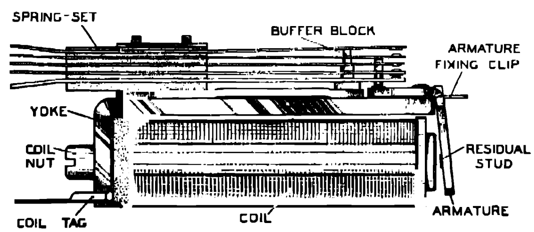


FIG. 148. P.O. 500-TYPE RELAY

are wound on similar iron cores which are magnetically connected together at their ends. It is apparent that if the current flows in the line winding only, by far the bulk of the resultant flux will circulate round the closed iron path formed by the core of the polarizing winding and the two yokes. Only a very small portion of the flux will pass through the main heel piece of the relay and the armature air gap, and hence the relay does not operate. Moreover, if a current also flows through the polarizing winding in such a direction that it assists the flux produced by the line winding in the closed iron path, there is still no tendency for any

appreciable flux to traverse the heel piece and armature air gap. If now the current in either the line winding or the polarizing winding (but not both) is reversed, then the magnetomotive forces of the two coils are opposing for any flux in the

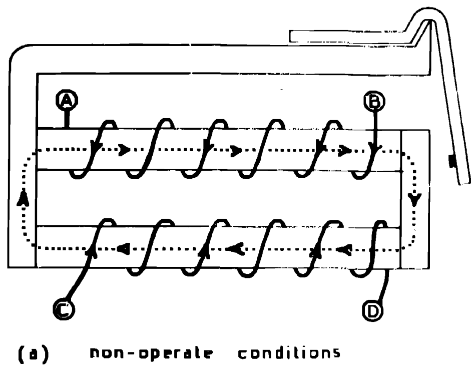


FIG. 149. PRINCIPLE OF THE SHUNT FIELD RELAY

closed magnetic circuit, but are assisting to produce a considerable flux through the heel piece of the relay, the armature and the armature air gap. The relay therefore operates under the above conditions.

The 3000-type shunt-field relay is illustrated in Fig. 150. The design follows the general arrangements of the standard relay except for the two coils and the small coupling yoke at their front ends. The 3000-type polarized relay is similar to the shunt-field relay except that the polarizing coil is replaced by a 36 per cent cobalt steel permanent magnet of rectangular cross-section. Owing to the greater size of the shunt-field and polarized relays, it is necessary to limit the contact load to two units in order that the relay can be accommodated in the standard mounting space.

Rectifier Polarized Relays. Apart from its limited load capacity, the shunt-field relay is somewhat liable to false operation as a result of surge currents in the line winding. In the latest circuits the shunt-field relay is being largely superseded by ordinary non-polarized relays in conjunction with metal rectifiers. Fig. 151 shows

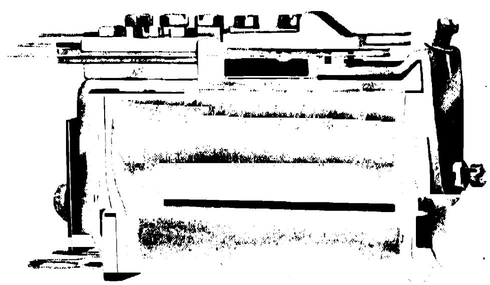


FIG. 150. SHUNT FIELD RELAY
3000-type.

a typical arrangement. A metal rectifier is placed in series with relay *D* such that the resistance of the circuit from *B* to *A* is high but so that current will readily flow from *A* to *B*. A second rectifier is placed in shunt with relay *D* to allow the passage of current from *B* to *A* if desired, without energizing relay *D*. This rectifier, moreover, prevents the development of a large p.d. across the series rectifier which might otherwise cause a breakdown of the rectifier elements. The impedance coil *I* is inserted when it is desired to maintain a high impedance to speech currents.

The shunt-field relay possesses one advantage over the rectifier polarized relay. With the latter

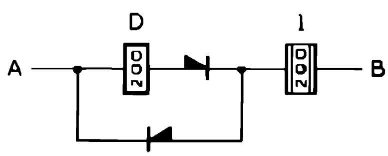


FIG. 151. RECTIFIER-POLARIZED RELAY

arrangement the operation or non-operation of the relay is controlled entirely by the direction of the signalling current, but with the shunt-field relay the current in the polarizing winding can be interrupted or reversed as required so that the relay will operate only at certain stages of the call.

A.C. Relays. Certain circuits require relays which will operate by the passage of low-frequency alternating currents. The ordinary fast telephone relay is unsuitable for the purpose owing to the release of the armature at each half-cycle reversal

of the current. Special relays have therefore been developed for a.c. operation and a typical design is shown in Fig. 152. A.C. relays are arranged to have an armature of considerable mass, and hence of great inertia, together with an arrangement which gives a very long armature travel. When the relay operates to a peak of current in one direction, the inertia of the armature prevents it from restoring sufficiently to open the contacts during the half-cycle reversals. Relays of this type can carry only a very limited spring load and the

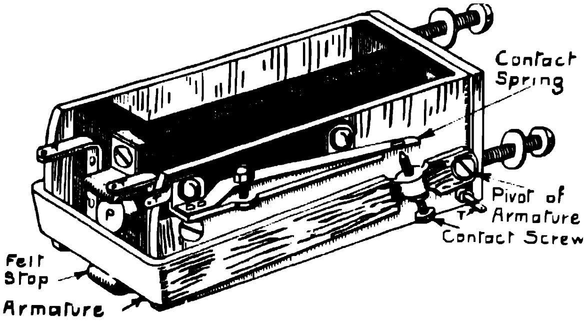


FIG. 152. TYPICAL A.C. RELAY
Relay No. 56B.

adjustments are often critical. In modern practice a.c. relays have been superseded by an arrangement of ordinary relays in conjunction with metal rectifiers.

Rectifier Shunted Relays. Fig. 153 shows the principle of the rectifier shunted electromagnetic relay as used on low frequency a.c. signalling circuits. The metal rectifier is connected directly across the terminals of a fully wound coil of some 1000 Ω resistance. It is usual to add a 2 μF condenser in series with the relay and rectifier combination to prevent the application of d.c. potentials which might cause breakdown of the rectifier. It will be seen that signalling current in one direction (I_1) passes almost wholly through the relay coil, the resistance of the rectifier being extremely high to currents in this direction. The opposite half-wave of alternating current (I_2) passes readily through the rectifier which effectively shunts the relay. The current in the relay is therefore a series of pulses, all in the same direction and at the same frequency as the applied a.c. signalling current. By the addition of a suitable slug to the relay it would be possible to arrange for the relay to remain operated between successive pulses of current through its coil. A much more efficient arrangement, however, is to avoid the use of slugs and to provide a highly inductive winding which can occupy the whole of the winding space on the relay. As the current commences to decline after the peak of each pulse, the e.m.f. induced into the relay winding tends to maintain the current through the coil. A low impedance path is available for this induced e.m.f. through the metal rectifier, and hence, during the decline of current in the relay coil, a heavy circulating current (I_3) flows through

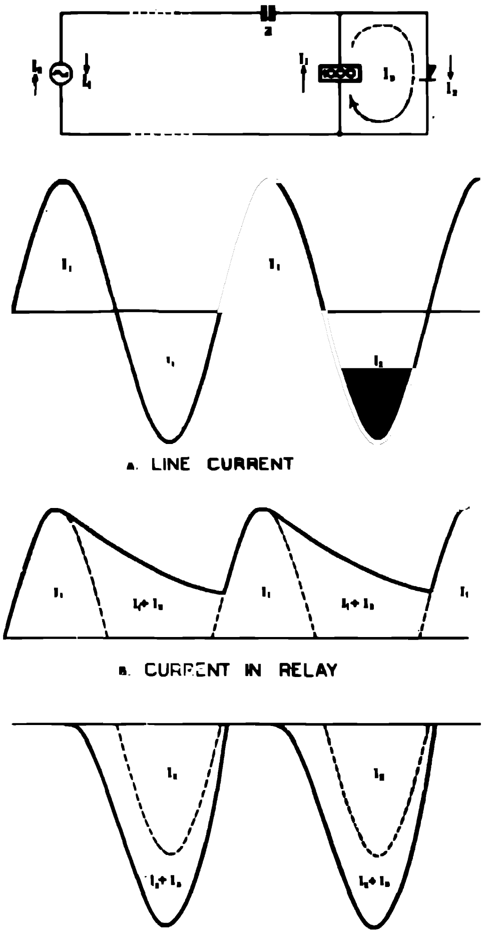


FIG. 153. RECTIFIER SHUNTED RELAY FOR A.C. OPERATION

the coil and rectifier in series. The effect is as shown at (B). By suitable adjustment of the relay resistance, turns, etc., the value of the circulatory current can be controlled and it is readily possible to design a circuit where the circulating current is sufficient to maintain the relay in its operated condition between the successive pulses of current from line.

High-speed Relays. The normal design of telephone relay has, under the best conditions, an

perate lag of 5 msec or more and it is unsuitable or use in circumstances where an extremely fast operation in the order of 1 msec is required. As will be seen later, these conditions exist in some automatic switching circuits where a relay must operate to stop the drive of a selector and where the stopping condition is applied only for a few milli-seconds. Fig. 154 shows a relay of special

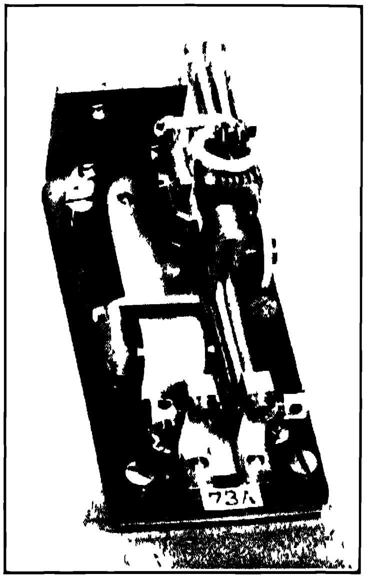


FIG. 154. HIGH-SPEED RELAY

design which was originally introduced by Siemens Brothers as the drive-stopping element of their No. 17 automatic system. The relay is provided with platinum contacts with a simple change-over action. Contact pressures are in the order of 15 to 20 g whilst contact bounce is of short duration. The relay is easy to adjust and will withstand considerable handling without adverse effect. With a 145 coil Ω and when operated in series with a 600 Ω non-inductive resistance from a 50 V supply, the relay will operate its break contact within 0·5 msec after the application of the current. The complete operation, i.e. to close the make contact of the change-over unit, is in the order of 1·5 msec. During release, the make contact opens within 0·3 msec of the disconnexion of the current and complete release within 1·3 msec is obtainable.

The mechanical arrangements of the relay are illustrated in Fig. 155. The fixed detail (1) carries a phosphor-bronze spring (2) which is channelled for stiffness at its lower extremity (3) and carries platinum contacts (4). A soft-iron armature (5) is welded to this spring and the armature butts against the unwound limb of the soft iron yoke (6). The armature and yoke are plated to prevent rusting and to preclude an iron-to-iron contact. The winding (7) is carried on a moulded insulating bobbin which is slipped on to the yoke and is retained by a brass wedging strip. Spring (2) passes through a slot in the buffer spring (8), the upper end of which is clamped with spring (2) to the fixed detail (1). The tension of spring (8) is controlled by screw (9) which passes through a tapped lug (10) and engages the buffer spring towards its free end. The mechanical forces on the armature of the relay are shown more clearly to the right of Fig. 155. The force on spring (8) due to the tension screw is shown at A where it may be considered as two components B and C. Force C holds the armature securely against the yoke whilst force B, pivoting about fulcrum F, imparts contact pressure in the direction R; thus contact (4) normally presses against break contact screw (11). When the relay is energized contact (4) changes over to press against contact screw (12). The design of the buffer spring (8) plays an important part in the successful performance of the relay

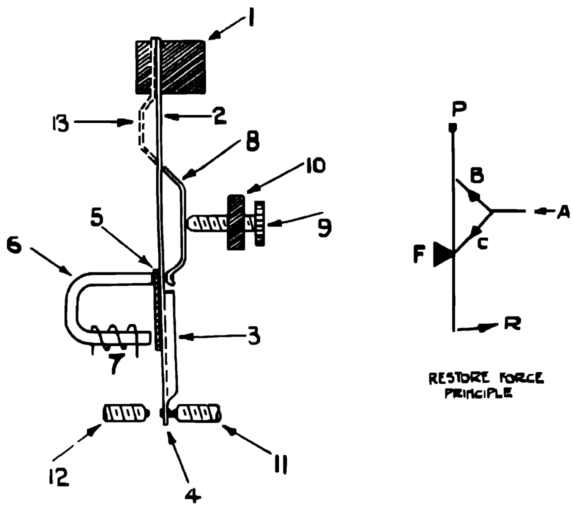


FIG. 155. MECHANICAL ARRANGEMENTS OF HIGH-SPEED RELAY

Firstly it is made flexible with the object of allowing good registration of the armature against the pole faces of the yoke and secondly, by this design, movement of the tension screw is not imparted wholly to the armature spring. This feature helps considerably in the accurate adjustment of contact pressure. The disposition and dimensions of the various moving parts are such that mechanical resonances tend to be damped out.

The adjustments of the high-speed relay are simple and are carried out as follows:

(*a*) Set the make contact screw so that it just touches the moving contact when the armature is held operated. Then turn the screw a further quarter of a turn to provide a residual air gap and tighten the locking screw.

(*b*) Adjust the break contact so that a 4 mil gauge will just pass between the make and moving contacts.

(*c*) Turn the tension screw until the break contacts can be opened with from 15 to 20 g pressure

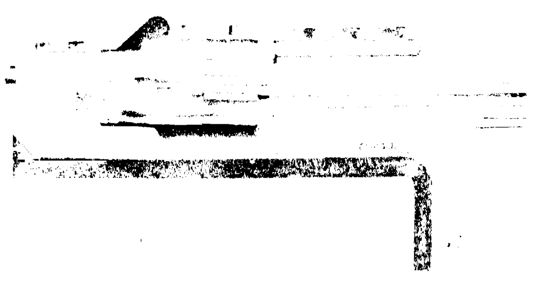


FIG. 156. THERMAL RELAY WITH FLICK CONTACT ACTION

when applied to the tip of the armature spring. In view of the very short armature travel it is of advantage, when adjusting the relay, to use a voltmeter or test lamp to indicate when the contacts open and close.

Thermal Relays. The most common type of thermal relay consists of a bimetal strip around which is wound a coil of resistance wire. The metals of the strip are chosen to have the greatest difference of expansion coefficient so that, when heated, the strip "bows" and operates the switching contacts. There is very little scope for this type of relay in telephony except where long time delays are required. The thermal relay has a number of disadvantages

(*a*) The power consumption is high.

(*b*) It is slow both to operate and release, the timing being affected by the ambient temperature, the interval since the last operation, etc.

(*c*) The closing or opening of the contacts is slow, unless a "snap" action is introduced mechanically.

(*d*) The life of the thermal element is short.

A modern form of thermal relay designed to line up with the Post Office 3000-type relay is illustrated in Figs. 156 and 157. The relay employs a flick contact action and the effects of change in ambient temperature are minimized by the introduction of a second unheated bimetal strip which opposes movement of the first bimetal strip when a change occurs in the atmospheric temperature. The relay provides only for simple contact units such as make, break, or change-over. The relay will operate in from 10 to 50 sec and releases in approximately 15 sec, and an adjustment is provided which enables these lags to be roughly determined. Thermal relays of this type are not normally

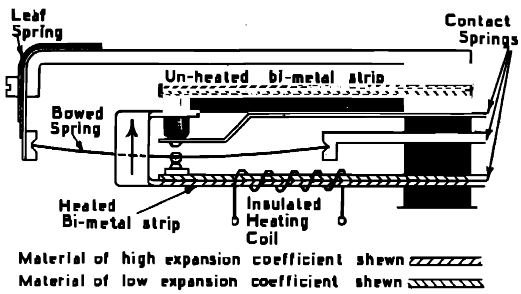


FIG. 157. MECHANICAL ARRANGEMENTS OF THE THERMAL RELAY

expected to maintain their operating and releasing lags within 25 per cent of the nominal values.

An alternative form of slow-operating relay based on thermal principles has been tried out with some success. It consists of an ordinary electromagnetic relay, across the coil of which is placed a thermal element. The thermal element is usually in the form of a resistance coil of iron or nickel-iron wire enclosed in a glass envelope. When the current is first switched on, the resistance of the element is low and so shunts away the current from the relay proper. As the filament heats up, the resistance increases, and the current through the relay

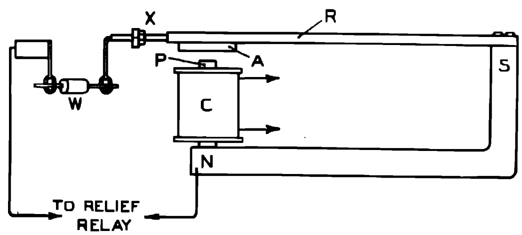


FIG. 158. PRINCIPLE OF THE MECHANICALLY TUNED VOICE-FREQUENCY RELAY

correspondingly grows until the operating point is reached. It has to some degree the disadvantages mentioned above, and involves marginal adjustments on the electromagnetic relay.

Voice-frequency Relays. Fig. 158 shows the principle of a relay mechanically tuned to receive voice-frequency signals of small magnitude. A soft-iron pole-piece *P*, carrying the coil *C*, is fixed near one end of the permanent magnet *NS*. The

iron armature A is mounted on a fairly stiff steel reed R, which is rigidly fixed to the frame of the relay at S. The free end of the reed carries a pair of hexagonal nuts X which can be adjusted within limits along the reed. The reed has a natural frequency of vibration which is governed by its mass, stiffness, etc., and which can be adjusted by positioning the nuts. If an alternating current is applied to the coil, the tractive force on the armature pulsates at the same frequency as the operating current. If the rate of vibration of the armature differs from the resonant or natural frequency of the reed, the amplitude of vibration is small. When, however, the frequency of the applied voltage approaches the resonant frequency of the reed, comparatively violent oscillation of the latter is produced. The free extremity of the reed carries a wire loop and a second loop is fixed to, but insulated from, the frame of the relay. A small cylindrical weight is suspended between the two loops and normally makes good electrical contact with both. When the relay is energized at the correct frequency, the vibration of the reed produces an intermittent contact between the weight and its supporting loops. The contact formed by the weight and loops is arranged to short-circuit a relief relay which is thus allowed to operate when the short circuit is partially removed by the vibration of the reed. Fig. 159 shows the practical design of a voice-frequency relay. The moving system is of the *balanced armature* type (i.e. the static pull on the armature is neutralized) in order to increase the sensitivity. The relay is arranged to plug into its mounting to facilitate removal for maintenance.

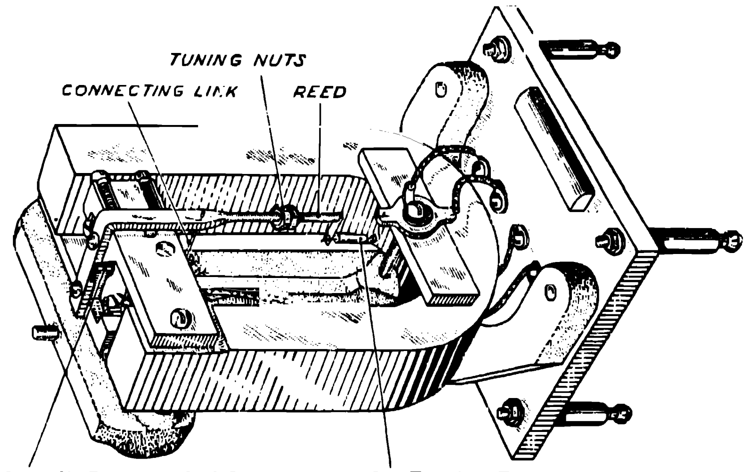


FIG. 159. VOICE-FREQUENCY RELAY

Mechanically tuned relays have been used successfully for 500 c/s ringing and for several other forms of voice-frequency signalling, but they have the inherent disadvantage of requiring critical adjustment and will in practice only function satisfactorily if the operating current is within fairly close limits. In modern practice, electrical filters, in conjunction with valve equipment, are largely superseding tuned relays.

Other Relays. It is not possible in this volume to describe the many types of relays which have been or are used for special purposes in telephony. Relays with operating lags of up to 6 min or more have been designed on the dash-pot or the ratchet-and-pawl principles, but modern practice favours the use of uniselector switches in conjunction with ordinary relays for obtaining very long operating or release lags. Mercury tube relays are now extensively used for the switching of high voltage or heavy current circuits. These relays are generally adaptations of the 3000-type standard relay and together with various forms of vibrating relay are described with reference to power supply in Vol. II.

In certain circumstances (notably in the C.C.I. system) relays are required to operate at a critical value of energizing current. Such relays follow, in general, the conventional design but are provided with a more sensitive means of adjusting the armature load, and the spring assembly is arranged to give a very small build-up of pressure as the armature is attracted.

Indicators. An indicator, in telephony, is an electromagnetic device so arranged that the passage of current through the coil operates a flag or disc to give a visual indication of the receipt of a calling signal. Indicators are of two main types, viz.:

(*a*) *Drop indicators* which are designed to give a continuous signal on receipt of a momentary or transient current, and

(*b*) *Eyeball or flag indicators* where the visual signal is given only for so long as the energizing current persists.

It is usual to provide local contacts on indicators of both types to complete an audible alarm circuit when required.

Drop Indicators. Fig. 160 shows the principle of the drop indicator. The electromagnet, which may

be of the single or double coil type, is arranged to operate an armature so pivoted that the armature rod releases a shutter which falls due to gravity and thereby exposes the number or designation of the circuit. After attention, the shutter must be

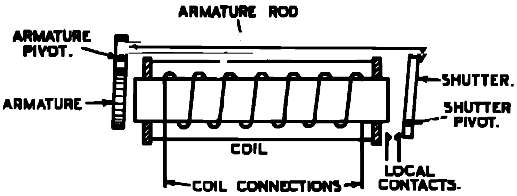


FIG. 160. PRINCIPLE OF THE DROP INDICATOR

restored by hand when it automatically links with the projection of the armature rod. Fig. 161 illustrates a common drop indicator of the double coil type, whilst Fig. 162 gives a partial cross-section of a single coil indicator. The coil of the latter indicator is enclosed in a tubular iron case which increases the impedance of the coil to speech currents and also provides a magnetic shield to minimize inductive interference between adjacent indicators. It is usual, therefore, to utilize the unshielded indicator when the circuit allows it to be cut out during the conversation, but in circumstances where it is necessary to leave the indicator across the speech conductors the high-impedance tubular indicator is invariably used. Whilst the drop indicator is normally used to receive a low-frequency alternating signalling current, it can of course be used for giving a visual indication of the receipt of a short pulse of

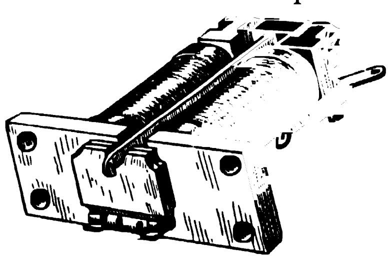


FIG. 161. TWO-COIL DROP INDICATOR
Indicator No. 1400A.

d.c. The great disability of the drop indicator is the necessity for hand restoration. Various devices have been introduced to provide self-restoring drop indicators. Fig. 163, for example, shows such an indicator which has been used on large type Private Manual Branch Exchanges. It consists of two coils (O and R) wound on a common core. The transient incoming signal passes through coil O and operates armature A which releases the front armature A' via the link D. The shutter itself (P) is pivoted at the top and is swung outwards and upwards when armature A' is released. To restore the indicator to normal, the front coil R is energized and the armature A' is attracted to lock under link D, thereby allowing the shutter P to restore. This type of indicator is now obsolescent, and on the later equipment ordinary eyeball indicators with a hold coil are used to give a continuous visual signal on receipt of an initial transient current.

Impulse Operation of Drop Indicators. Difficulties are sometimes experienced with switchboards of the cordless type due to false operation of the exchange line indicators when an extension dials through to the exchange. With this type of switchboard, the exchange line drop indicators are permanently across the line when an extension is extended to the exchange. In automatic areas,

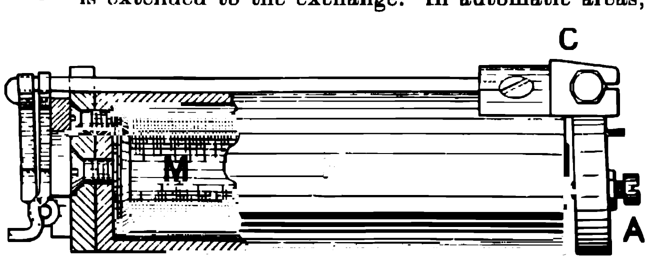


FIG. 162. TUBULAR INDICATOR
Indicator No. 1000A.

the change of p.d. on the lines during impulsing sometimes causes the indicator to drop. In these circumstances, a special indicator which is insensitive to impulsing is fitted. The armature (Fig. 164) is of the rotary type similar to that of the eye-

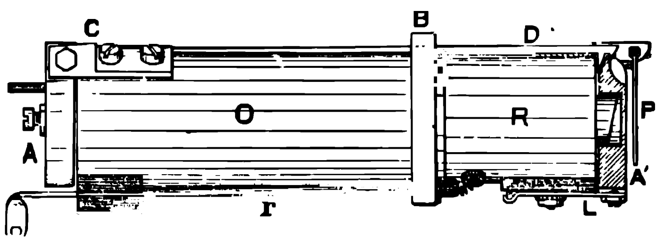


FIG. 163. ELECTROMAGNETICALLY RESTORED DROP INDICATOR
Indicator No. 4D.

ball indicator, and a projection engages with the trip lever when the armature is almost fully operated. The construction is such that whilst the shutter is released by a sustained energization of the magnet coil, very short current pulses due to impulsing do not cause false operation.

Eyeball Indicators. In this type of indicator (Fig. 165) the calling signal persists only whilst current is actually flowing through the coils of the

indicator. The electromagnet is of the single coil type and the moving system consists of a pivoted carriage on one side of which there is a white or coloured portion of a hollow sphere and on the other side a curved tongue-shaped soft-iron armature. When the electromagnet is energized, the carriage revolves about its axis so that the "eyeball" fills the aperture in front of the indicator. The magnetic circuit of the indicator consists of the centre core with the two side members in parallel and is completed at the front by the armature. When the coil is energized, the magnetic forces are such as to attract the maximum volume of iron to complete the magnetic circuit. The armature thus rotates so that the wider parts of the armature are brought in front of the pole face progressively. An extension (B) of the armature engages with a contact spring (A) to complete a local circuit when the indicator is operated. When the current in the indicator coil ceases, the indicator restores to its normal position under the influence of gravity.

Sixpenny Indicators. This type of indicator, which is shown in Fig. 166, is designed to mount on a horizontal shelf and, when energized, a white or coloured disc about the size of a sixpence is made to appear at a horizontal window in the shelf. The upward attraction of the armature A raises the light aluminium disc D in front of the window W by movement of the long cranked armature lever L which is pivoted at P.

Subscribers' Meters or Registers. Electromagnetically operated counting mechanisms of the Veeder type are employed to a considerable extent for the registration of call charges. The mechanisms are known as *meters* or *registers* and owing to the large number required it is desirable that they should be small and relatively inexpensive. On the other hand, it is essential that meters, possibly more than any other component, should be reliable in operation. The number of turns and resistance of a meter depend upon the system of registration. In some cases local contacts are provided to indicate when the meter has fully operated or, alternatively, to provide a locking circuit for the meter to avoid any possibility of more than one operation during each call. The development of multi-fee metering in modern exchanges does, of course, preclude the use of locking type meter circuits.

Meter mechanisms may be either of the *direct acting* type in which the Veeder mechanism is moved during the attraction of the armature, or of the *reverse acting* type where the counting mechanism is operated during the release of the armature. Both types have been used to a considerable extent but, in general, the reverse acting type is favoured in modern practice.

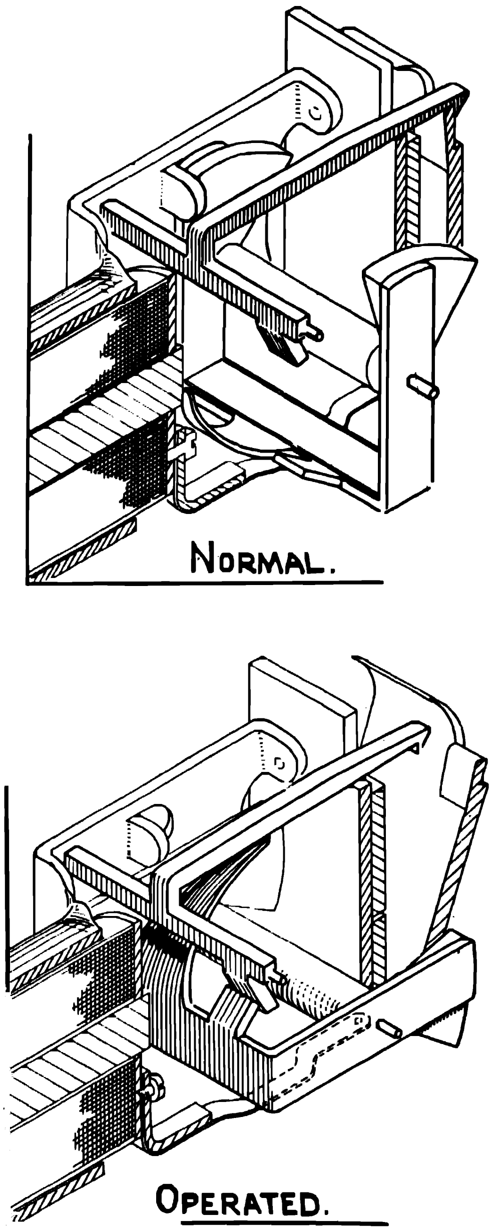


FIG. 164. DROP INDICATOR WITH ROTARY ARMATURE
Indicator No. 4000A.

Post Office 100-Type Meter. In conformity with the policy of standardization, a new design of

subscriber's meter or register has recently been evolved. The meter is known as the Post Office No. 100 type and is illustrated in Fig. 167. The meter

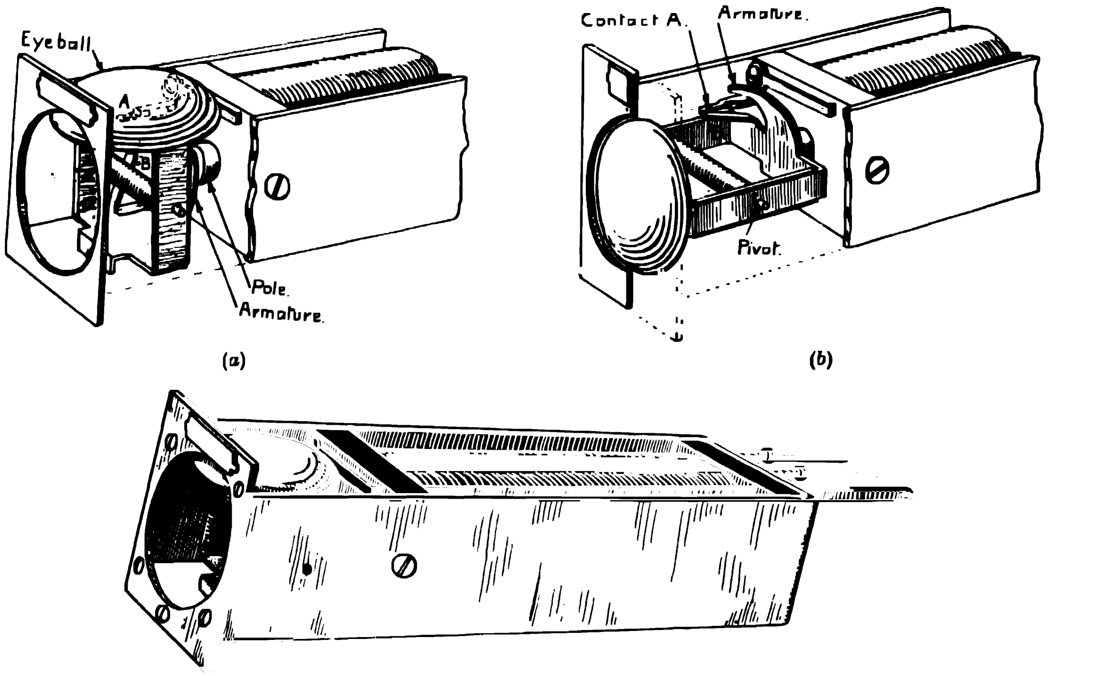


FIG. 165. EYEBALL INDICATOR
Indicator No. 400B.
(a) Normal. (b) Operated. (c) General view.

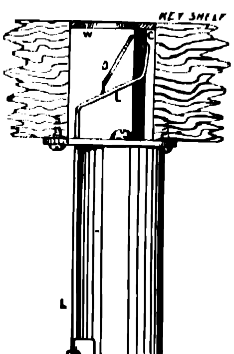


FIG. 166. SIXPENNY INDICATOR
Indicator No. 600A.

has all the advantages of earlier types, but is more compact, whilst special attention has been given to the problem of minimizing wear of the moving parts. The compactness has been made possible by the arrangement of the armature, which is pivoted towards the rear of the meter and lies parallel to the axis of the coil (Fig. 168). The meter is "reverse-acting," i.e. during the operation of the armature the pawl slips over one tooth of the ratchet wheel without moving the number drums. Breaking of the current allows the spring-loaded armature to return and the pawl, which has dropped in engagement with the ratchet wheel, carries the latter forward one-tenth of a revolution. A pair of contacts mounted on the frame are fitted when required to complete a local circuit on the operation of the meter.

The armature has a knife-edge pivot and is held in position by a helical spring. Residual studs are fitted on the under-side of the armature to prevent sticking and to take the impact when the latter is attracted. The armature bearing is formed by a plate mounted on the yoke or heel-piece of the meter. This plate is capable of adjustment for aligning the armature in the frame and for the correct spacing of the secondary air gap at the front of the pole-piece. The front end of the core turns upwards at right angles to form the pole face whilst the front cheek of the coil is of moulded insulating material and has a recess moulded into it which forms ledges to act as a buffer block for the local contact springs. A circular nut clamps the coil and yoke to the frame, and the ends of the windings are brought out to a tag block attached to the heel end of the frame. An "L"-shaped plate, the vertical part of which is slightly bent at the top, forms the pawl, and projections on the under-side of the horizontal part constitute the

pivot. Movement of the units drum in a backward direction is prevented by a detent in the form of a flat spring which is capable of adjustment in relation to the ratchet teeth. This detent also exerts a backward pressure on the ratchet wheel to lock it against the tip of the pawl. The back stop against which the armature rests when the meter is unoperated is shaped to allow of adjustment by bending. This adjustment is essential for positioning the units drum in relation to the viewing aperture in the cover. Raising or lowering this stop advances or retards the units drum. The absence of spindles for the pawl and armature eliminates the possibility of looseness in bearings due to wear, and the long stroke of the armature allows an ample margin on the pawl movement. The number drums themselves are die-castings of tin-antimony alloy running on polished steel spindles. At the end of a revolution of the units wheel, a notch engages with a tooth on the first intermediate pinion which is also in mesh with the teeth on the "tens" drum. The movement given to the pinion by the units drum advances the "tens" drum one-tenth of a revolution. The subsequent drums are similarly operated and a maximum reading of 9999 can be accommodated. No provision is made for restoring the drum mechanism to zero. The new meter will pulse operate at a frequency up to about 300 impulses per minute and is therefore much better for rapid pulse operation than previous designs. The 100-type meter when fitted with a 500 Ω coil (Meter No. 100A) has an operate current in the order of 25 mA.

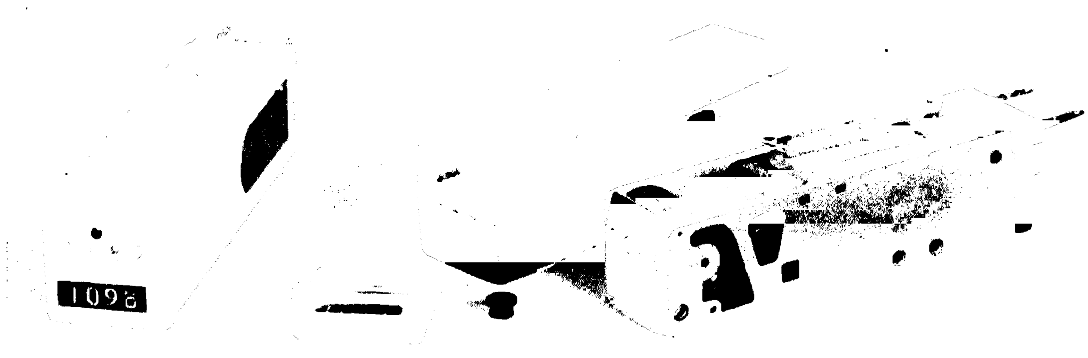


FIG. 167. SUBSCRIBER'S METER
P.O. 100-type.

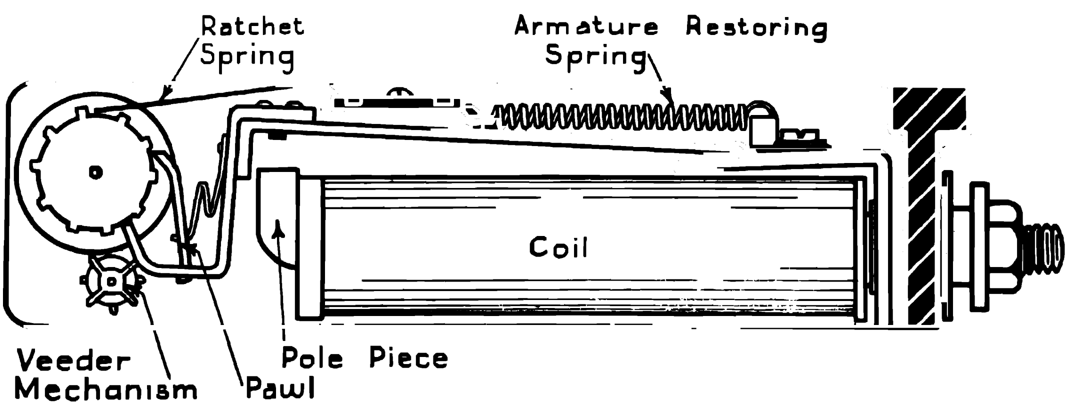


FIG. 168. PARTIAL CROSS-SECTION OF 100-TYPE METER

Impulse-driven Veeder Clocks. Fig. 169 shows a typical electromagnetically driven clock of the Veeder type. It is used to some extent on manual switchboards for time indication or to check the accuracy of master clock pulses. There are four index wheels which are more widely separated than

those of a subscriber's meter. The first wheel gives the number of hours, the next two wheels indicate the number of minutes and the right-hand wheel gives the time to the nearest one-tenth of a minute. It is apparent that this clock is designed for use with a 6-sec energizing pulse.

The mechanism is of the direct-acting type and is of interest since it is substantially similar to that

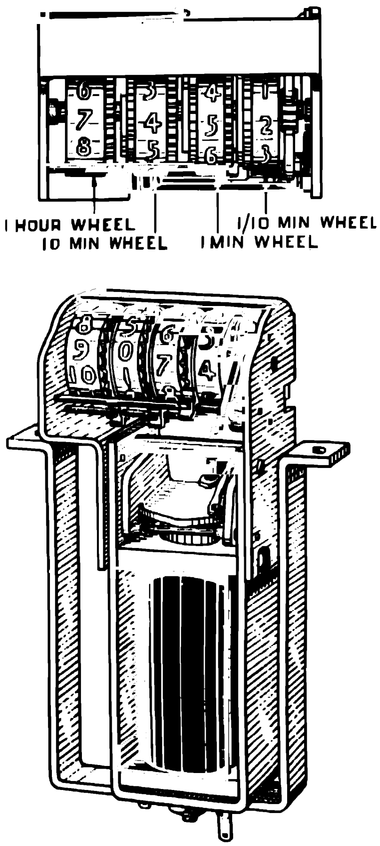


Fig. 169. Impulse-driven Switchboard Clock
Clock No. 38.

of a large number of subscribers' meters of the pre-100 type.

Signal Lamps. Indicators are now becoming more and more replaced for signalling purposes by signal lamps of special design. Not only does a lamp give a more striking calling signal, but it has the important advantage of requiring only a fraction of the space necessary for an indicator. On the other hand, lamp signals require considerably more current than an indicator, and cannot usually be connected directly in a line circuit, but must be used in conjunction with a signalling relay. In general, lamp signals are used in public exchanges and other large offices where the power consumption is of secondary importance, whilst indicators are retained at subscribers' premises, etc., where the power drain must be kept to a minimum and where economy of switchboard space is not vital.

The standard signalling lamp (No. 2) used in the Post Office is cylindrical in form and about $\frac{1}{4}$ in. dia. with an overall length of $1\frac{3}{4}$ in. (Fig. 170).



Fig. 170. Standard Switchboard Signal Lamp
Lamp No. 2.

The filament is led out of the glass envelope with wires of a metal suitable for sealing in glass and, externally, the lead-in wires are soldered to nickel-plated brass connexion plates cemented to the sides of the bulb. The tip or end-piece is made of a moulded heat-resisting material, and is wedge-shaped at the end to facilitate insertion into the lamp jack. The end piece is of a distinctive colour to indicate the voltage of the lamp. Until a few years ago, all lamps were of the carbon-filament type, but recently a number of metal-filament lamps have been introduced and it is probable that metal filaments will be universal within a short period. Carbon-filament lamps have been superseded for general lighting for the past twenty-five years or more and it is no longer economical for the lamp industry to continue the manufacture of a few carbon-filament lamps for special purposes. The conversion of telephone signal lamps from the carbon type to the metal-filament type introduces some difficulties due to the different characteristics of the two types.

Carbon has a negative temperature coefficient and hence the resistance of a carbon-filament lamp decreases as the voltage across the lamp is increased (Fig. 171). Metal-filament lamps have, on the other hand, a positive temperature coefficient so that the resistance increases with rise of applied voltage. For the same rated wattage, a metal-filament lamp has a "cold resistance" very much less than that of a carbon lamp. It is therefore not always possible to fit metal-filament lamps in a circuit designed for carbon lamps without considering the effect on the remaining components of the circuit.

The different resistance characteristics also affect the light output. With a small applied voltage, the low resistance of the metal-filament lamp produces a large heating effect (E^2/R) which,

in turn, causes the lamp to glow under conditions when the carbon lamp would not be visibly alight. For example, when the applied voltage is about 75 per cent of the rated voltage, a metal-filament lamp glows at approximately half its normal brilliance (Fig. 172), but under the same conditions

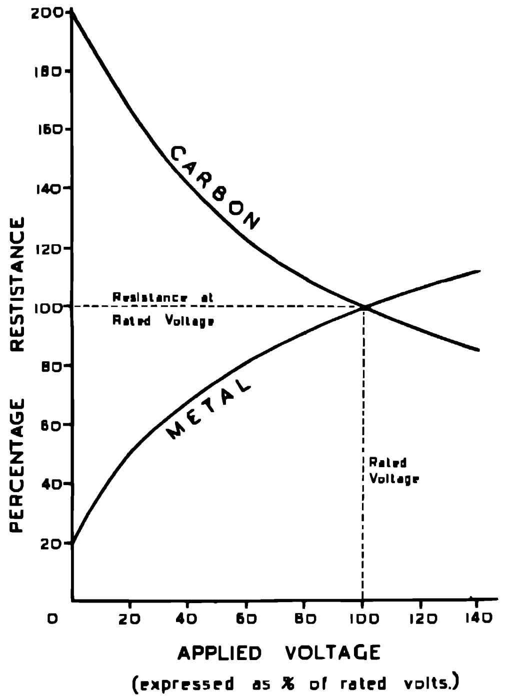


FIG. 171. RESISTANCE/VOLTAGE CHARACTERISTICS OF CARBON AND METAL FILAMENT LAMPS

there is no appreciable glow from a carbon lamp. This difference may introduce difficulties in circuits where a lamp is to be extinguished by the application of a shunting resistance. In modern circuit design practice signal lamps are, wherever possible, placed in separate "local circuits" so that any changes in the electrical constants of the lamp do not affect other components of the circuit.

This following table gives some details of typical signalling lamps. In this particular selection, the 6 V and 17 V lamps are of the metal-filament type whilst the remainder are carbon-filament lamps. The 6 V metal filament lamp is particularly efficient and is the standard lamp for all circuits on sleeve control switchboards (q.v.).

Colour of end piece	Voltage	Current (A) at normal volts	Power (W)
Grey	6	0·040	0·24
Orange	17	0·045	0·76
Yellow	24	0·107	2·57
Blue	40	0·068	2·72
White	50	0·100	5·00

The high wattage of the 50 V lamp is due to the difficulty of accommodating a longer or thinner filament in the small envelope of the standard lamp. Metal- and carbon-filament lamps can readily be distinguished by the different construction of the filament. Carbon lamps have a bow or loop filament, whilst metal-filament lamps have a longer and closely coiled filament generally supported at one or more points along its length.

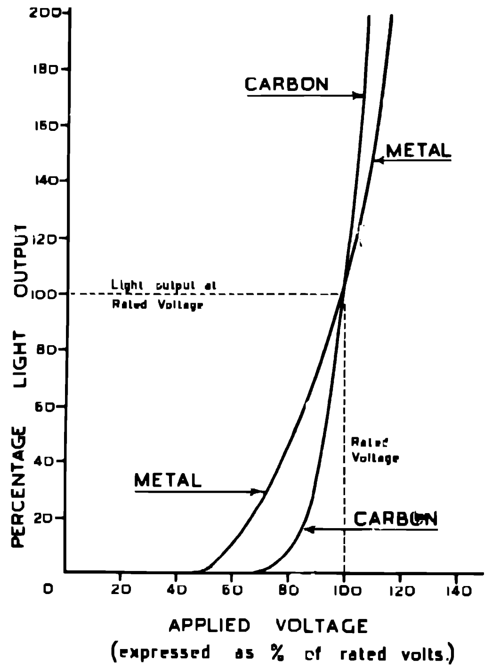


FIG. 172. VARIATION OF LIGHT OUTPUT WITH CHANGE OF APPLIED VOLTAGE

Lamp signals are not, of course, so permanent as electromagnetic indicators, but a life of some 1000 hr is obtained with tungsten filament lamps, and an average of some 300 hr is usual for carbon-filament lamps. The lower life of carbon-filament lamps is due largely to the blackening of the bulb, which gradually reduces the light output of the lamp to the minimum permissible for satisfactory use.

EXERCISES VII

1. Give a detailed constructional sketch of a modern telephone type relay fitted with one make-before-break contact assembly. State the type of material used for each component part of the relay associated with the magnetic circuit and spring set assembly, and the reasons for the choice of material in each case. (*C. & G. Telephone Exchange Systems I*, 1947.)

2. Describe, with the aid of sketches, the construction and mode of operation of the relays employed, in a keysending system, for the reception of currents of voice frequency. (*C. & G. Telephony, Grade III*, 1942.)

3. Describe, with the aid of sketches, the changes that occur in the distribution of the magnetic flux in a shunt-field relay under working conditions. (*C. & G. Telephony, Grade I*, 1941.)

4. Describe a type of thermal relay in which compensation is made for changes in ambient temperature. How does the operating time of a thermal relay vary with the value of the current through it?

5. Describe the P.O. 3000-type relay, and indicate how contact bounce and contact failures are minimized in the design.

6. Discuss the methods of adjusting and checking the performance of various types of telephone relay.

7. Describe an indicator suitable for use on a d.c. signalling circuit where the current persists for the duration of the calling signal.

8. Describe, with sketches, the construction of a drop indicator which is immune from false operation due to surge currents of short duration.

9. Sketch a modern type of subscriber's meter or register. Compare the merits of direct acting and reverse acting meter mechanisms.

10. What are the relative merits of signal lamps and indicators? Give sketches showing the electrical characteristics of signal lamps of the carbon- and metal-filament types.

CHAPTER VIII

THE PRINCIPLES OF LOCAL LINE SIGNALLING

SATISFACTORY telephonic transmission requires that two wires shall be provided between telephone instruments. In small internal installations the cost of the interconnecting line is small and, if necessary, one or more additional conductors can be provided for signalling purposes without undue increase in the overall cost. When, however, the lines between telephones become longer—and particularly when external lines are involved—it is economically impracticable to provide additional conductors for signalling. In general, therefore, it is the object of the signalling engineer to provide all the required facilities on the basic pair of wires necessary for speech transmission. For circuits within a building it is, nevertheless, often more economical to provide one or two additional wires if by so doing savings can be effected in the amount of apparatus required.

Apart from electrical considerations, signalling methods are largely determined by the facilities involved when a subscriber merely wishes to advise his exchange that a call is required—as in manual systems—as compared with the dialling of a subscriber connected to an automatic exchange in which the signals must not only advise that a call is required but must also indicate to the automatic plant exactly *what* is required. Similarly, in certain circumstances signalling in both directions at the same time is desired as, for example, when one exchange A calls for another exchange B and it is required that the circuit shall simultaneously pass the calling signal of A and the answering signal from B.

Basically, telephone signalling may be divided into:

(*a*) direct current signalling; and

(*b*) alternating current signalling.

The latter may, in turn, be subdivided into:

(i) low-frequency signalling usually of 17–25 c/s; and

(ii) voice-frequency signalling when the frequencies fall within the transmission range of telephone speech, e.g. 500 c/s.

It is the purpose of this chapter to describe those principles of signalling which may be used between a subscriber and his local exchange. Signalling between exchanges is somewhat more involved and is considered later in Chapter XIII.

The Trembler Bell. A trembler bell associated with a push button at the calling end is possibly the simplest form of signalling. Fig. 173, which nowadays is a common arrangement in most houses for door bells, etc., shows the principle of the trembler bell. It consists of an electromagnet formed by the coils C_1 and C_2 connected together by the soft-iron yoke Y. The magnetic circuit is completed through the air gaps and the armature

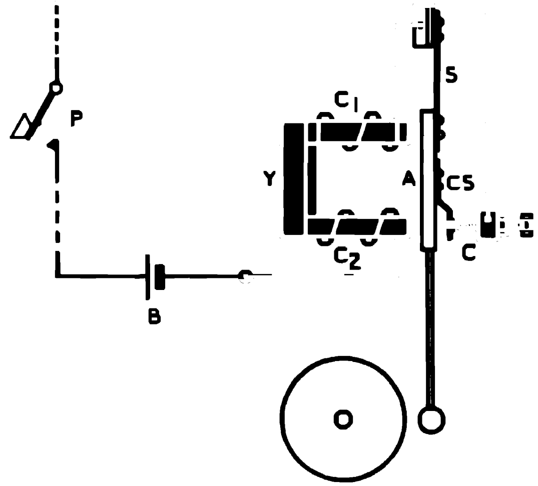


FIG. 173. TREMBLER BELL

A, which is also of soft iron and is held in position by the flat steel spring S. The armature is fitted with a contact spring CS which is maintained in electrical contact with the adjustable contact screw C by the tension of S. When the button P is depressed, current flows from the battery B through coils C_1 and C_2 via the contact screw and spring. The coils are wound so that their magnetic effects assist in producing a high flux-density in the air gaps, and the armature is thus attracted. Shortly after the armature commences to move, the electrical circuit is broken at the contact screw and the pull of the magnet dies down as the flux decays. The moving system is, however, comparatively heavy and the momentum of the armature allows it to continue for some time after the circuit is broken. When the hammer strikes the bell gong, the natural recoil and the tension of the spring S return the armature to normal. At a late stage in

the return stroke, the circuit is remade at the contact screw, but the movement is continued a little farther against the tension of the contact spring *CS* due to the momentum of the armature assembly and to the comparatively slow rise of current (and hence of flux) due to the inductance of the coils. Thus, so long as the press button is operated, the bell armature vibrates at a regular speed, the hammer striking the gong at each forward stroke.

A trembler bell can, of course, be wound to any resistance to suit the e.m.f. of the battery and the resistance of the signalling circuit, but it is apparent that whatever the resistance, the energy consumed must always be fairly high on account of the mechanical work involved. With a trembler bell, as with any other highly inductive circuit, there is a high e.m.f. induced in the windings at the moment the circuit is broken. This e.m.f. tends to produce sparking at the interrupter contacts with the consequent disintegration of the latter. To prevent this, both the contact spring and the contact screw are tipped with a hard metal which will not oxidize and which is not fusible except at very high temperatures. Platinum fulfils this condition but, owing to its prohibitive cost, a less expensive alloy is almost invariably used. The high e.m.f. due to self-inductance may be considerably reduced by the use of a suitable spark-quench circuit but, even if it were possible completely to absorb this voltage, trembler bell signalling as applied to telephony has the great disadvantage that wires external to the bell are rapidly changing potential as the contact is made and broken. It is therefore very difficult to avoid interference with adjacent speech conductors.

Local Battery Signalling. For economic reasons, it appears desirable that the battery required for the energization of the transmitter should also suffice for signalling. A possible circuit for two simple local battery telephones with trembler bell signalling from the speaking battery could be designed on the lines of Fig. 174. This circuit, in addition to providing the normal conditions for speech transmission, enables one telephone to ring the other by the operation of a press button *P*. It has nevertheless the following serious limitations:

(*a*) The calling telephone bell is in parallel with the called telephone bell and, apart from the unnecessary annoyance, the local bell acts as a shunt on the distant bell thereby reducing the available current supplied to the line.

(*b*) The receiver and induction coil of both telephones are also in parallel with the bells thereby further increasing the shunt on the distant bell.

(*c*) The direct current flowing through the receiver tends to produce demagnetization with a consequent reduction in efficiency should the receiver be incorrectly connected.

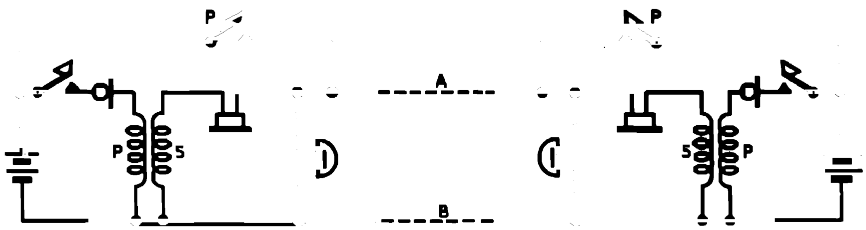


Fig. 174. Elementary Circuit for Two Local Battery Telephones with Direct Current Signalling

(*d*) The p.d. across the receiver circuits during ringing varies considerably as the trembler contacts break and remake, thus producing an unpleasant noise in the calling subscriber's receiver.

(*e*) The bells are permanently connected across the lines and thereby introduce a transmission loss which, owing to the necessarily low d.c. resistance of the bell, must be appreciable. (It is, of course, the *impedance* of the bell which determines its effect on transmission but it is difficult to obtain a high impedance coupled with a low d.c. resistance.)

(*f*) If both press buttons are operated at the same time, unguarded batteries are fed out from each telephone and this would cause a heavy circulating current if the line conductors became reversed. Similarly a short circuit on the line would produce a heavy current when either of the press buttons were depressed.

These defects are illustrative of the type of problem encountered in signalling. A better and more practical arrangement is shown in Fig. 175. The calling press button or key (*P*) is of the change-over (break-make) type and is arranged to disconnect the local telephone circuit during calling, thereby obviating defects (*a*) to (*d*). To prevent the bell remaining in shunt with the speech path during conversation (*e*), the circuit is arranged automatically to switch the lines from the bell circuit to the speaking circuit when the receiver is

lifted from its rest or hook. Such contacts (*SW*) are known as *switch-hook* or *cradle switch* contacts and are almost invariably employed on telephone circuits to change over from signalling to speaking conditions. A separate press key is shown for completing the transmitter circuit, but if desired this may be combined with the switch-hook contacts.

Magneto Ringing. The trembler bell as a means of giving an audible calling signal is not entirely satisfactory. Mention has already been made of the high inductive e.m.f. produced at the break contacts and of the rapid change of potential of the wires external to the bell. Apart from these considerations, the interrupter contacts of a trembler bell have a high fault liability with resulting high maintenance costs. For these reasons, a.c. bells which will respond to a low-frequency signalling current in the order of 17 to 25 c/s have for many years been the universal calling signal of the telephone instrument. By short-circuiting the interrupter contacts, the ordinary trembler bell can be made to respond to alternating current signals. Under these conditions the armature is attracted during each half-cycle, and hence the frequency of vibration of the hammer is twice that of the applied a.c. The sensitivity of this arrangement leaves much to be desired. Some improvement can be made by polarizing the bell by the introduction of a permanent magnet at some point in the magnetic circuit (coils, yoke, or armature). During one half-cycle of applied a.c., the flux due to the current assists the permanent magnet and the armature is attracted. During the other half-cycle the flux due to the current opposes that of the permanent magnet and the armature is not operated. In the polarized bell, therefore, the armature is operated once per cycle. The slower speed of vibration of the bell hammer produces a more pleasing ring especially where large, loud ringing bells are required. But apart from this, the introduction of a permanent magnet materially increases the sensitivity of the device. The principle is substantially similar to the polarization of a receiver which has already been described in Chapter III. Briefly, by the introduction of a permanent magnet the change of tractive force on the armature is very much greater than that which would be produced by the applied alternating current only. The sensitivity of the a.c. bell can be further increased by omitting the armature restoring spring and arranging that the armature is restored by each alternate half-cycle of ringing current. This principle is adopted in the design of a.c. bells in telephony.

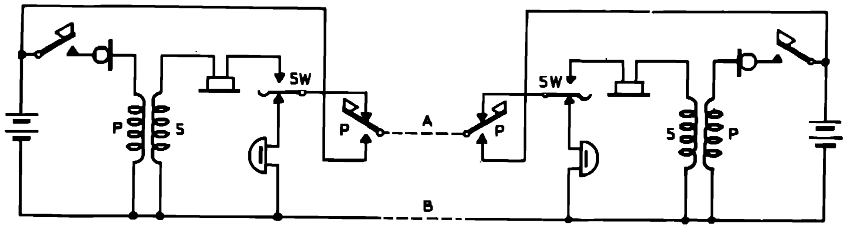


Fig. 175. Improved D.C. Signalling Circuit

The Magneto Bell. The operation of the magneto or a.c. bell is shown diagrammatically in Fig. 176. The two coils *A* and *B* are coupled at one end by a soft-iron yoke and the armature is pivoted centrally near the free extremities of the coils. A permanent

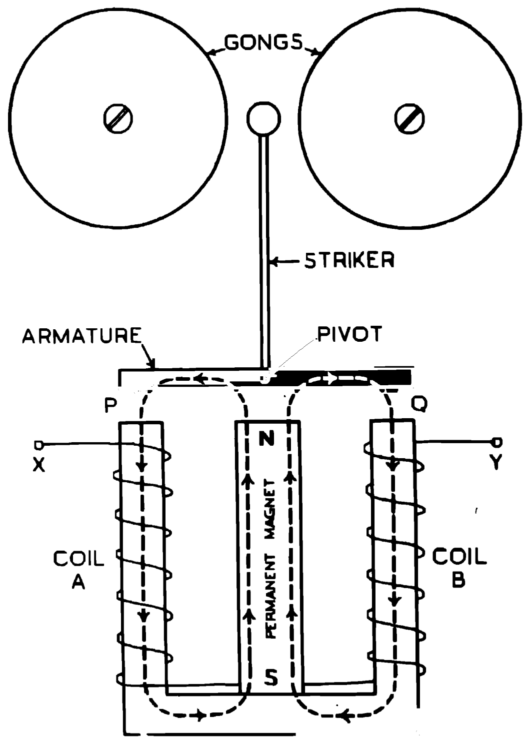


Fig. 176. Principle of the Polarized A.C. Bell

magnet is arranged so that one end is fixed at the centre of the yoke and the free end is in close proximity to the centre of the armature. Under static conditions the flux due to the permanent magnet traverses two parallel paths. The first path is through the left-hand portion of the armature, air gap P, coil A, and the left-hand part of the yoke.

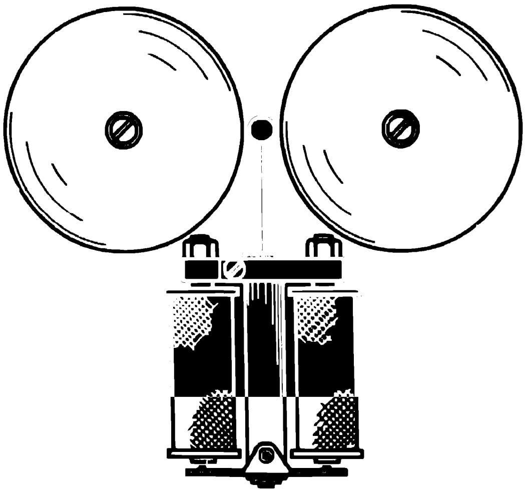


Fig. 177. Magneto Bell
Bell No. 59A.

The second path is via the right-hand portion of the armature, air gap Q, coil B, and the right-hand portion of the yoke. With the armature in the position shown, the magnetic characteristics of these two paths are identical and the flux-density in air gap P is equal to that at air gap Q. The forces and turning moments on the armature are therefore balanced, and there is no tendency for the armature to be attracted to either pole. It is apparent, however, that the armature is in a state of unstable equilibrium and any slight mechanical disturbance will cause it to move towards one or other of the pole-pieces. Any such movement reduces the air gap at one side and extends the length of the opposite air gap. This in turn produces a greater flux-density at one air gap and a reduced density at the other, thereby causing the armature to move over until one end is resting on the core of the electromagnet. In practice, this is the normal static position of the armature.

If now a current is passed through the coils of the bell from terminal X to terminal Y, the magnetomotive force due to the current opposes the flux due to the permanent magnet at air gap P, and at the same time assists the flux of the permanent magnet at air gap Q. The flux-density in air gap P is thereby reduced, whilst that at Q is increased and the armature moves over to the right. If now the current is reversed and flows from Y to X, the magnetic force of the current opposes the permanent magnet flux in the right-hand magnetic circuit, i.e. air gap Q, whilst the permanent magnet flux is assisted in the left-hand magnetic circuit, i.e. air gap P. The flux-density and hence the tractive force at air gap P is now much greater than at Q and the armature swings over to the left. If, therefore, an alternating current is passed through the coils of the bell the armature will move to the right and left for each half-cycle of current, thereby causing the striker to engage with each of the bell gongs once per cycle. It should be noted that once the armature commences to move, the initial unbalance of the tractive force at the two air gaps is still further increased by a reduction in the length of the air gap at the more powerful pole and a corresponding increase of the length of the other air gap. This trigger effect makes the bell extremely sensitive, particularly to surges of current of short duration. Great care must be taken in circuit design to avoid bell tinkling due to surges of current in the coils.

Fig. 177 shows the general assembly of the Post Office standard magneto bell (Bell 59A) for subscribers' instruments and the construction is shown in more detail in Fig. 178. The coils are each of 500 Ω and are fixed to a substantial steel yoke by single clamping nuts. The permanent magnet is of cylindrical form bored at the lower end to take a brass armature bearing pin and a bearing pin clamping screw. The armature is a light iron stamping with a clearance hole at the centre for the permanent magnet. Brass residual studs are fitted to prevent the complete closure of the magnetic circuit between the armature and the core and so to avoid the possibility of the armature sticking. The armature can be readily removed by loosening the clamping screw at the lower extremity of the bar magnet and by withdrawing the armature bearing pin. Adjustment of the armature air gap and of armature alignment is obtained by loosening the magnet clamping screw and by adjusting the position of the permanent magnet in the yoke. The bell is usually mounted by fixing the yoke to the chassis of the instrument by means of tapped holes at the rear of the yoke. Normally, both bell coils are connected in series, but in special circumstances where a low d.c. resistance is required, the coils are connected in parallel to give an effective resistance of 250 Ω compared with the total resistance of 1000 Ω with both coils in series.

The impedance of the standard magneto bell at an average speech frequency of 800 c/s is in the order of 17 000 Ω at an angle of some $\angle 50°$. With both coils in parallel the impedance is reduced to

approximately 4300 Ω with substantially the same angle.

The Magneto Generator. The low-frequency alternating signalling current required for the operation of bells may be produced either by a motor-driven alternator at the telephone exchange or by a small permanent-magnet type alternator of simple design rotated by means of a crank handle. A typical *magneto generator*, as such generators are usually called, is illustrated in Fig. 179. Fig. 180 shows a general view of the same generator with the permanent magnets removed, whilst Fig. 181 gives a partial cross-section of a similar generator. The generator consists fundamentally of three or four permanent magnets of horse-shoe shape clamped to a common pair of pole-pieces. Between the pole-pieces is an (—) section soft-iron armature which is drum wound with silk-covered or enamelled wire to a total resistance of from 400 to 500 Ω. One of the connexions to the armature winding is made to the frame whilst the other is terminated on an insulated contact at one end of the armature spindle. The driving end of the spindle is provided with a brass pinion which engages with a larger gear on the driving shaft to give a speed ratio of 3 : 1 to 4 : 1. The driving gear wheel is not fixed rigidly to the crankshaft. A pin fitted to the crankshaft rides in a V slot in the boss of the gear and is held in the centre of the V by the axial tension of a helical spring. When the crank is turned, the pin moves along one or other side of the V notch, thereby moving the crankshaft in an axial direction against the helical spring. After about one-sixth of a revolution the pin reaches the end of the V, and the driving gear and crankshaft now rotate together to drive the generator. The axial or lateral movement of the crankshaft is used to operate contact springs at the end of the shaft. This automatic switching arrangement is used to change over the circuit connexions to the calling condition during rotation of the generator crank. In the older circuits the springs were connected to cut out the bell circuit and to connect the generator to the line, and hence have become known as the *cut-out contacts* of the generator.

Wave Form of Magneto Generator. The e.m.f. generated in any conductor moving in a magnetic field depends on the rate at which the conductor cuts magnetic lines of force. If a straight conductor or loop is rotated in a *uniform* magnetic field (Fig. 182), the e.m.f. induced in the conductor varies in accordance with a sine curve. In the magneto generator these conditions do not apply since the distribution of flux between the pole-pieces is neither uniform nor constant. Fig. 183 shows the magnetic circuit with the armature in various positions. At (*a*) the armature is so placed that it provides a minimum reluctance to the flux between the pole-pieces *N* and *S*. The conductors

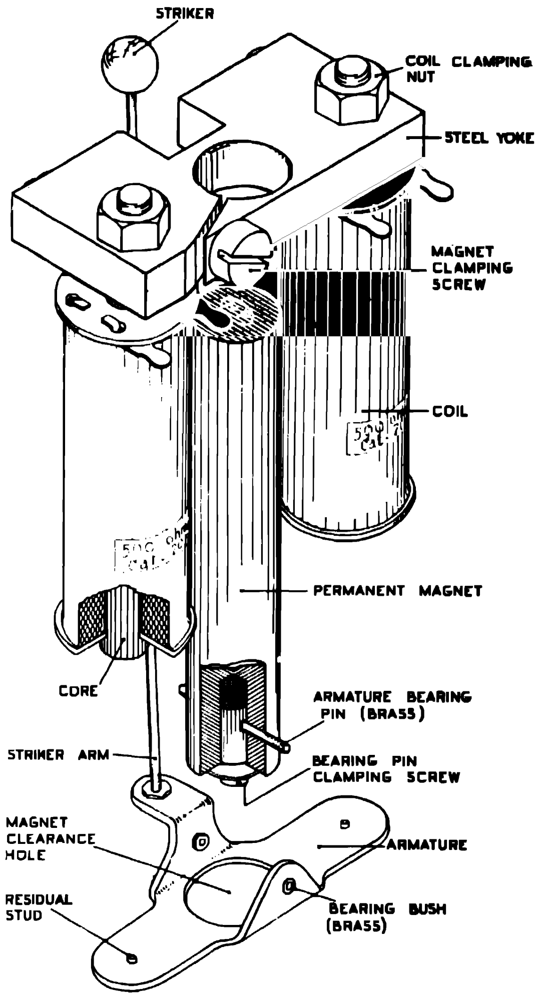


Fig. 178. Details of a Modern Magneto Bell
Bell No. 59A.

are therefore moving in a very weak field and the position of the armature is such that any small induced e.m.f.s are mutually opposing to give no effective e.m.f. at the terminals. As the armature now rotates in, say, a clockwise direction, the flux continues to take the path of least reluctance and the field between the pole-pieces is distorted as shown at (*b*). The bulk of the flux will traverse the low reluctance path through the armature core and hence the conductors themselves are moving in a comparatively weak field. Hence

the e.m.f. generated is less than the sine curve value which would exist if the field between N and S were uniform.

As the armature rotates further, flange X commences to leave pole N and the other flange Y approaches the pole. At this position the reluctance of the path between N and S via flange X is rapidly increasing whilst the reluctance of the alternative path from pole N through flange Y to pole S is rapidly decreasing. As a result the flux moves over rapidly from top to bottom so that when the armature arrives at the position shown at (*d*) the bulk of the flux is traversing pole Y. Thus when the armature moves from the position shown at (*b*) to that shown at (*d*), not only are the conductors cutting the field substantially at right angles but the field itself rapidly cuts across the conductors from top to bottom. The snap of flux very considerably augments the e.m.f. generated during this part of the rotation. The resultant voltage wave is somewhat as shown in Fig. 184. The broken curve indicates the sinusoidal wave which would be produced if the design of the generator were such that the flux distribution were uniform and constant.

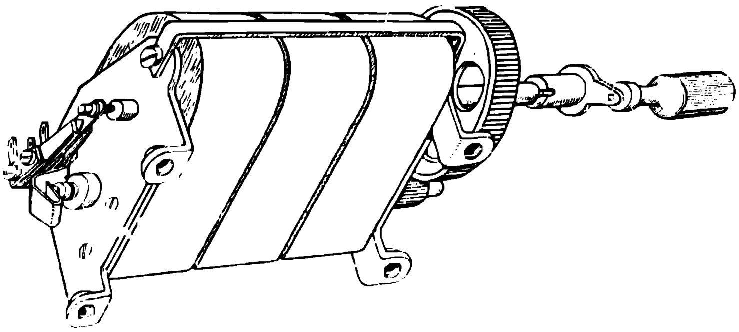


FIG. 179. TYPICAL MAGNETO GENERATOR
Generator No. 4.

The design of magneto generators is largely governed by cost considerations. Nevertheless the function of the generator is to operate such apparatus as indicators and bells which are essentially current-operated devices and, at the normal low frequencies of ringing, their response is more or less in relation to the peak voltage applied to them.

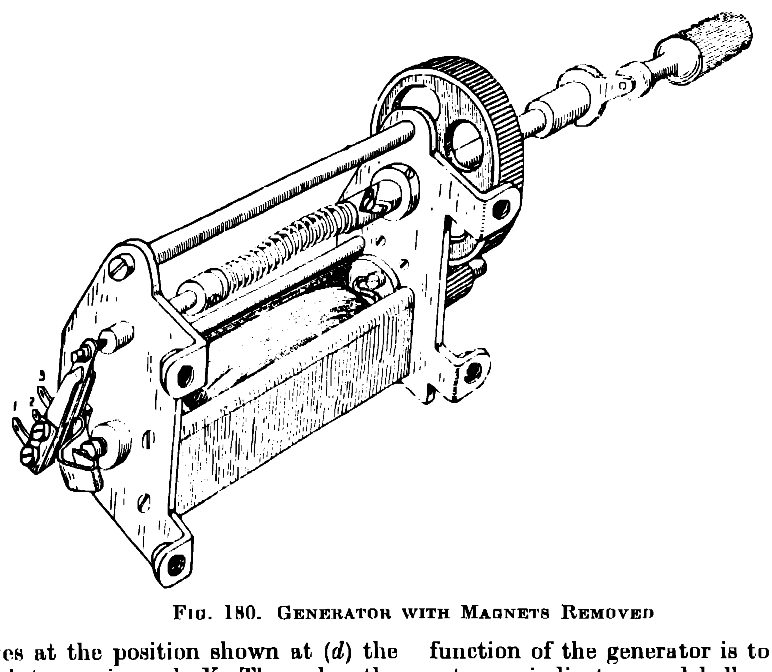


FIG. 180. GENERATOR WITH MAGNETS REMOVED

The abnormal peak voltage of a magneto generator may thus drop an indicator or produce an audible ring when a generator of similar power output but producing a wave of sinusoidal form might fail. On the other hand, a peaky wave form is undesirable in any telephone system since from Fourier's Law such a wave consists of the fundamental and a number of higher frequency harmonics. Some of these harmonics fall within the audio range and are a possible source of interference on adjacent telephone circuits. In actual practice the danger is not serious if reasonable precautions are taken.

Alnico Generator. Figs. 185 and 186 illustrate the constructional details of a new type of generator recently introduced. The special feature of the generator is the semi-cylindrical magnet which is cast from an aluminium-nickel-cobalt alloy known as "Alnico" (10% aluminium, 20% nickel, 10% cobalt). This alloy when magnetized requires a very high coercive force to effect demagnetization and hence a much shorter magnet will suffice. On the other hand, the remanent or residual magnetism per sq cm after magnetization is somewhat less than with tungsten steel, and a greater cross-sectional area is required for the same total flux. Nevertheless for the same performance, an Alnico magnet has a volume approximately two-thirds of that required with tungsten steel. The smaller volume and lower specific gravity of the new steel enables a generator to be designed of approximately twice the output of the older generator illustrated in Fig. 179, with a 25 per cent reduction in the size and weight.

The malleable cast-iron armature is wound with enamelled wire and runs on pivot bearings which are force-greased at each end by means of the cheek bearings, adjustment being provided at the cut-out end of the generator. The current is collected by means of carbon brushes. This, together with the pivot bearings and a slight "backing off" of the trailing tips of the armature flange, helps to reduce the high starting torque which is a common difficulty on all magneto generators due to the "snap" of flux previously explained. With the bakelite moulded case (Fig. 187) the overall dimensions are 4½ in. high, 4½ in. wide, and 4 in. deep.

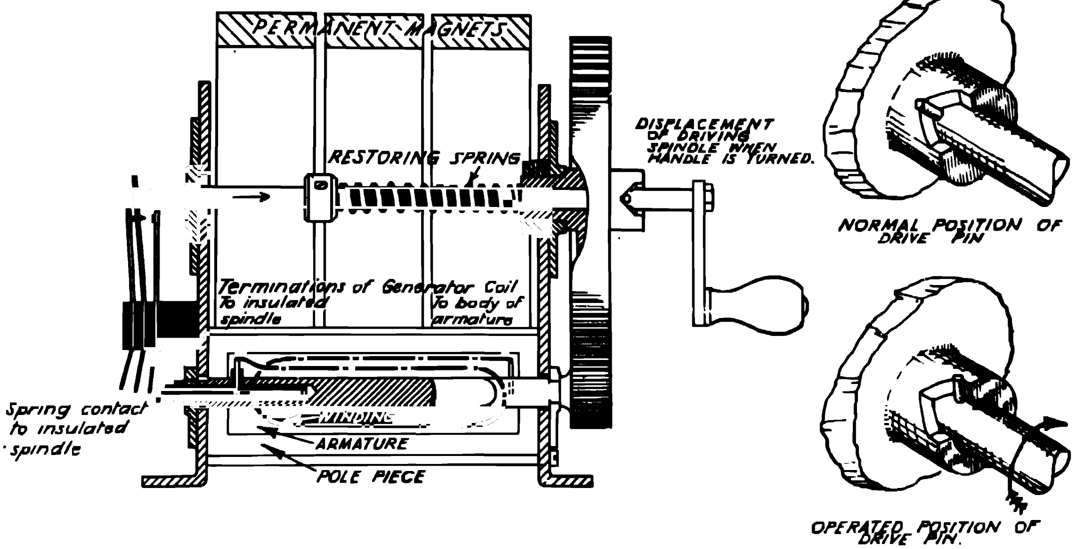


FIG. 181. PARTIAL CROSS-SECTION OF MAGNETO GENERATOR

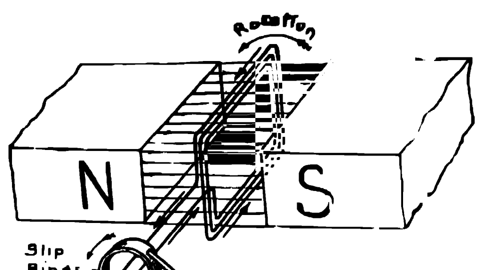


FIG. 182. PRINCIPLE OF AN A.C. GENERATOR

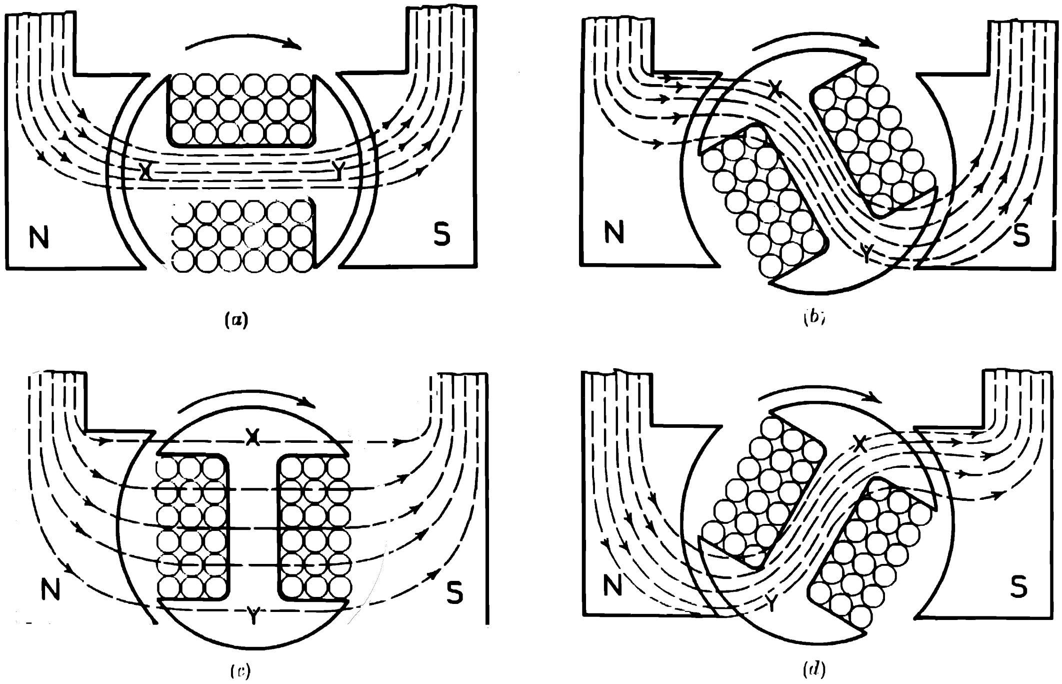


FIG. 183. CHANGES OF FLUX DISTRIBUTION IN A MAGNETO GENERATOR

(a) No e.m.f. (b) Small positive e.m.f. (c) Maximum positive e.m.f. (d) Small negative e.m.f.

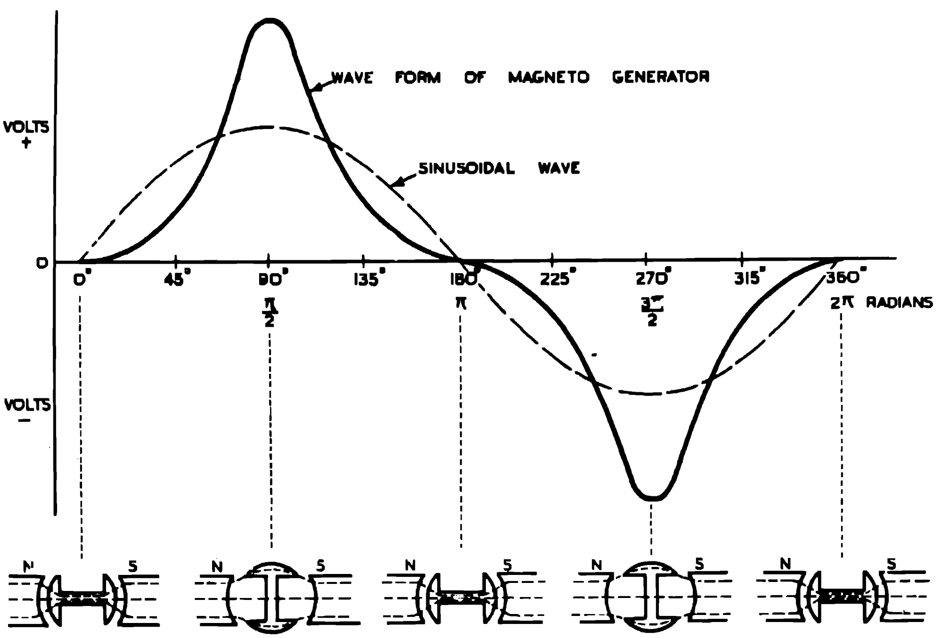


FIG. 184. WAVE-FORM OF A MAGNETO GENERATOR

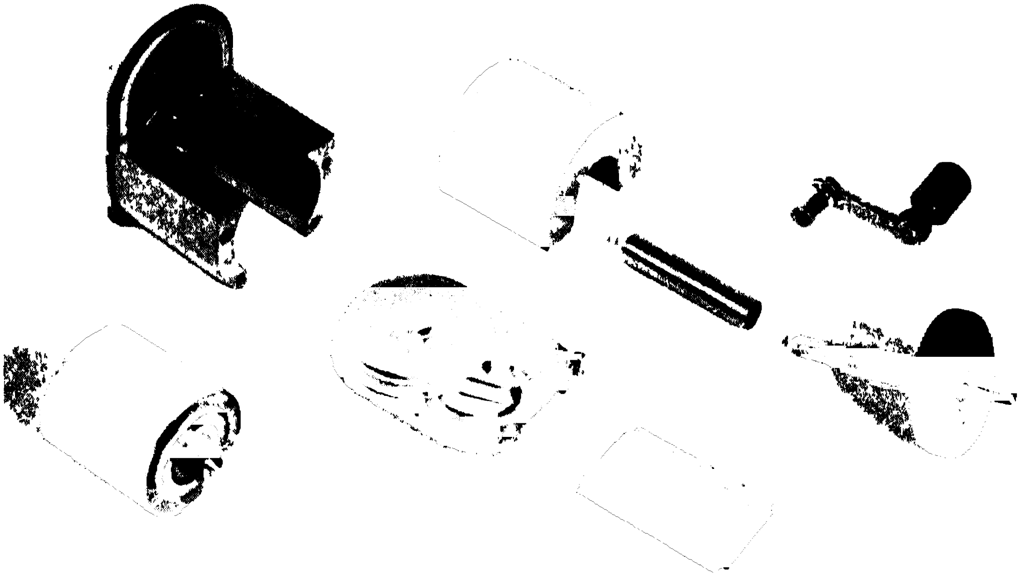


FIG. 185. COMPONENT PARTS OF NEW GENERATOR

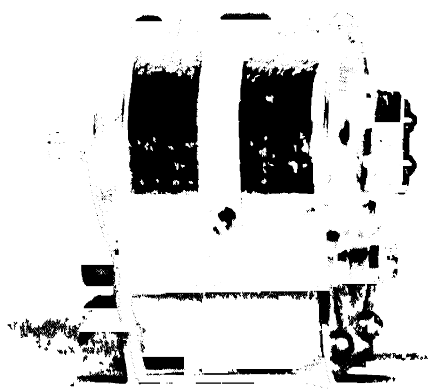


FIG. 186. NEW TYPE OF GENERATOR WITH ALNICO MAGNET
Generator No. 26A.



FIG. 187. NEW GENERATOR IN MOULDED CASE

Signalling Requirements. A modern telephone system requires the following signalling facilities between a subscriber and his local exchange:

(*a*) A calling signal from the subscriber to advise the exchange that a call is required.

(*b*) A clearing signal from the subscriber at the end of a conversation to indicate that the connexion may be broken down.

(*c*) A ringing signal from the exchange to advise the subscriber of an incoming call.

(*d*) An answering signal from the subscriber to show that he has replied to an incoming call.

It is practicable and usual to utilize the same electrical conditions for both the calling and answering signals since they are never required together on any one call. This leaves a minimum requirement of three distinctive and separate signal circuits. The universal use of the a.c. type of call bell at the subscriber's telephone necessitates the employment, in all cases, of low-frequency magneto current for the ringing signal. The calling and

TABLE IV

COMPARISON OF VARIOUS SIGNALLING METHODS

Scheme	Calling Conditions	Clearing Conditions	Advantages	Disadvantages
1	Magneto Ring	Magneto Ring-off	(a) Can be used on lines of high resistance when d.c. signalling is impracticable. (b) Does not require a condenser to separate a.c. ringing circuit unless a d.c. answering signal is required.	(a) Signals are transient and either drop indicators or locking relays are required. (b) Clearing signals are unreliable since they depend upon the subscriber turning the generator at the end of each call. (c) Magneto generators at each telephone involve high initial and maintenance costs. (d) An answering signal cannot readily be provided without resort to d.c. signalling.
2	Break of d.c. loop	Remake of d.c. loop	(a) Automatic indication is given of disconnexion faults on lines. (b) Clearing signal is automatic and "positive," i.e. the restoration of the loop can operate a clearing indicator directly.	(a) Requires a permanent current round the subscriber's loop when the circuit is idle. (b) Cannot be used in conjunction with Central Battery transmission.
3	One or both lines earthed	Removal of earth from one or both lines.	(a) Automatic indication is given of earth faults on the lines. (b) Does not require a condenser to separate the a.c. ringing and d.c. calling circuits	(a) Presence of earth during speech requires isolating and balancing impedances. (b) Earth connexion at each telephone increases the fault liability. (c) Clearing signal is "negative."
4	Removal of earth from one or both lines.	Restoration of earth on one or both lines.	(a) Automatic indication is given of disconnexion faults on the lines. (b) Clearing signal is "positive."	(a) Requires a permanent current when the circuit is idle. (b) Earth connexion at each telephone increases the fault liability.
5	Make of d.c. loop.	Application of earth to one line.	(a) Automatic indication is given of short-circuit faults on the line. (b) Clearing signal is "positive." (c) Does not require a condenser to separate the a.c. ringing and d.c. signalling circuits.	(a) Earth connexion at each telephone increases the fault liability. (b) Reversal of lines is not permissible.
6	Make of d.c. loop.	Break of d.c. loop.	(a) Automatic indication is given of short-circuit faults on the line. (b) Absence of earth simplifies the telephone and increases reliability.	(a) Requires a condenser to separate the a.c. ringing and d.c. calling circuits. (b) Requires the introduction of a relay or other device to give a positive clearing signal.

clearing signals can, on the other hand, be a.c. or d.c. and the signal can be either the starting or interruption of a current. The signalling circuit can, moreover, be completed over both wires of the speaking pair or alternatively the return circuit can be provided through earth connexions at the subscriber's telephone and at the exchange. These possible variations in the signalling circuits, coupled with the method of supplying energizing current to the subscriber's transmitter, constitute the main differences between the various types of local exchange systems.

Possible Signalling Schemes. Owing to the high ohmic resistance of external lines, any scheme for calling and clearing which involves a signalling battery at the subscriber's premises is impracticable on economic grounds. Similarly, any form of a.c. signalling other than the use of a simple magneto generator is not permissible on account of the high cost of the terminal apparatus. The calling and clearing signals from a subscriber's telephone are therefore limited to the operation of a magneto generator or to the starting or disconnexion of a direct current from a battery applied to the speaking conductors at the exchange. Table IV (p. 136) shows the various alternatives available and summarizes the more important features of each signalling scheme.

Schemes 2 and 4 were tried in the early days of telephony in the various *permanent current* systems but were quickly abandoned owing to the complications arising from the continuous line current when the circuit is idle. It is interesting to note, however, that the permanent current principle is still used in special circumstances, e.g. police and fire alarm systems, where it is vital that a disconnexion of the line should be revealed at once. Scheme 3 is impracticable on transmission grounds and, in any case, it has no merits (but a number of disadvantages) when compared with schemes 5 and 6. Scheme 1 has, for many years, been highly successful in the magneto system, but it is now obsolescent in view of the manifold advantages of automatic d.c. signalling. Scheme 5 was adopted in the Post Office Central Battery Signalling System No. 1, which was designed some forty years ago. The earth clearing feature of the C.B.S. No. 1 system was found to introduce maintenance difficulties and complications on junction circuits. It has now therefore been superseded by the C.B.S. No. 2 system, which employs loop calling in conjunction with disconnexion clearing (Scheme 6). This last principle has proved very satisfactory and is the standard scheme for Central Battery exchanges and for all automatic systems.

The Magneto System. The telephone of the original magneto system consisted of a simple local battery transmission circuit with a magneto bell and generator for signalling. The circuit was arranged so that, when the receiver was lifted, the bell was disconnected at the switch-hook contacts to prevent the shunting of speech currents. There were several arrangements of generator cut-out contacts to avoid ringing the local bell during the operation of the generator. In some of these, the generator and bell were arranged in series and the contacts were wired so that when the generator was at rest the armature was short-circuited but, when the handle was rotated, the short circuit was

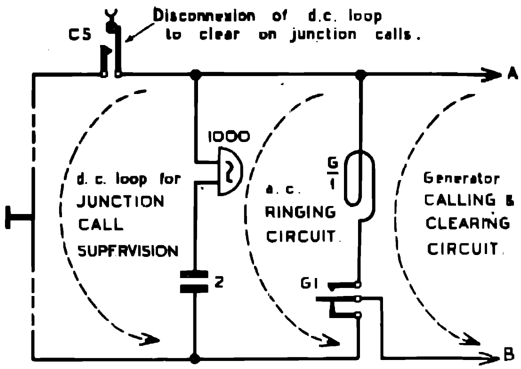


FIG. 188. BASIC SIGNALLING CIRCUITS OF A MODERN MAGNETO TELEPHONE

removed from the armature and placed across the bell. In other circuits, the bell was connected across the speaking pair via the break contact of the generator cut-out and the generator was connected across the pair via the make side of the cut-out contacts. In the original magneto system no d.c. signalling between the subscriber and the exchange was provided, and hence there was no need to provide a condenser in the bell circuit.

Fig. 188 shows the general signalling arrangements of a modern magneto telephone. The generator is connected between the telephone and the line with the cut-out contacts (*G*1) so arranged that the whole of the telephone circuit, including the bell, is disconnected when the generator handle is turned. This arrangement enables the same telephone to be used (without the generator) on other signalling systems. The bell circuit is permanently across the speaking pair to avoid the fault liability of break contacts on the cradle switch. The impedance of the bell to speech frequencies is so great that the transmission loss is negligible. The introduction some years ago of automatic timing devices for trunk calls made automatic clearing from the calling subscriber's switch-hook essential. All magneto telephones were

therefore modified to give automatic d.c. clearing on junction and trunk calls whilst retaining the original "ring-off" signal for local calls. The d.c. signalling is provided by inserting a 2 μF condenser in the bell circuit so that, when the receiver is replaced at the end of a call, the d.c. loop is broken at the cradle switch contacts.

The circuit arrangements of the magneto system during calling, ringing, and speaking are indicated in more detail in Fig. 189. The transmission circuit of the telephone is of the local battery type already described in Chapter V. When the subscriber wishes to make a call he turns the handle of the generator, which applies low-frequency ringing current to line via contacts **G1**. This ringing current operates the drop indicator *L* at the exchange so as to expose the indicator flap. When the call is answered and extended to the required party, the calling indicator *L* is disconnected from the circuit and is replaced by a supervisory indicator *S*. The supervisory indicator is connected across the speaking pair and hence is of high impedance. On calls extended over a junction, a supervisory condition is forwarded for so long as the receiver is off the rest. This supervisory condition is a loop via ***CS*1**, the induction coil windings and ***CS*2**. When the subscriber hangs up at the termination of the call the d.c. loop is interrupted at *CS*1 and *CS*2 to give a disconnexion as the clearing signal for junction calls. If, on the other hand, the call is of a local nature the subscriber clears by giving the generator one or two turns to operate the supervisory indicator *S* at the exchange. On incoming calls the operator at the exchange throws the ringing key which applies ringing current to the *A*-wire and earth to the *B*-wire. This current traverses the 2 μF condenser and the bell to give an audible calling signal.

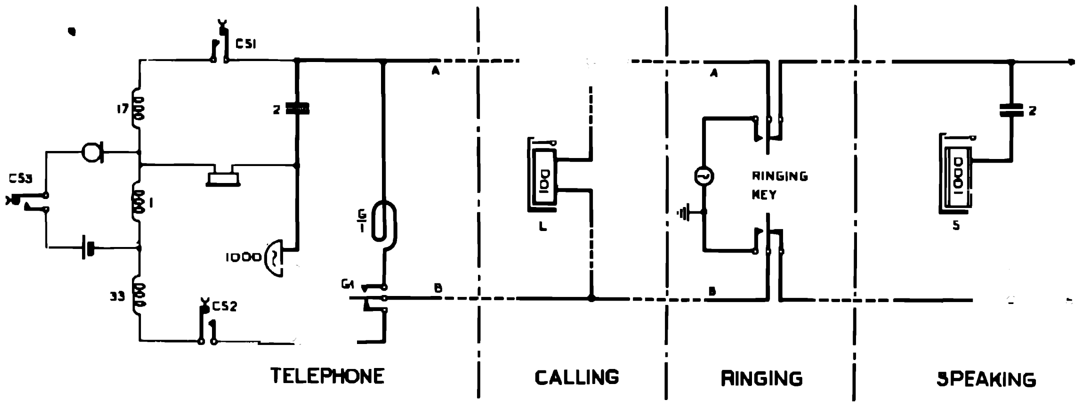


FIG. 189. CALLING, RINGING, AND SPEAKING CONDITIONS OF THE MAGNETO SYSTEM

The C.B.S. No. 1 System. The C.B.S. No. 1 system was designed in the early stages of the development of manual switching in Great Britain primarily for small exchanges in rural areas. The use of local battery telephones with a loop-call, earth-clearing signalling system gave some considerable advantages over the magneto system, but at the same time the system did not require the extensive secondary cell power supply equipment of the C.B. exchange. It has already been stated that the earth clearing system has in the course of time been proved inferior to the more modern disconnexion clearing, but at the time of its introduction, it possessed certain advantages. Application of earth at the telephone instrument gives a positive clearing signal on a supervisory indicator at the exchange without the necessity of introducing a relay. The earth-connected bell does, moreover, avoid the necessity of a condenser in the subscriber's instrument—a material factor in the early days of telephony when condensers were comparatively expensive. On the other hand, the presence of an earth in the signalling circuit is a prevalent source of faults and other troubles due to differences of earth potential, etc. The bell resistance in the d.c. signalling circuit is a further handicap and necessitates the use of a low resistance bell. This in turn results in complications when paralleled instruments are required. It is also apparent that line reversals are inadmissible on the C.B.S. No. 1 system.

Fig. 190 shows the basic elements of a C.B.S. No. 1 telephone circuit. When the telephone is at rest, the earthed bell is applied to the *A*-wire of the circuit, the bell coils being connected in parallel to give a total d.c. resistance of 250 Ω in order to reduce the resistance of the clearing circuit. When the receiver is lifted from the rest, the earthed bell

is disconnected at the cradle switch contacts (*CS*) and the d.c. calling and supervisory loop is extended to the exchange. The more detailed connexions of the subscriber's instrument circuit and the conditions at the exchange during calling, ringing, and speaking are illustrated in Fig. 191. The transmission circuit is the standard auto-transformer arrangement already described in Chapter V with the addition of cradle switch contacts (*CS*3) to

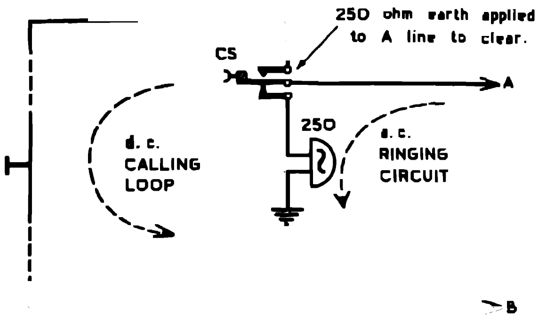


FIG. 190. BASIC SIGNALLING CIRCUITS OF A C.B.S.1. TELEPHONE

complete the local battery circuit. Contact *CS*1 changes over from the loop calling to earth clearing conditions whilst *CS*2 isolates the local battery from the line when the telephone is not in use. At the exchange, the calling loop operates the battery connected indicator *L* and, when the call is answered and a connexion is established, indicator *L* is removed from the line and is replaced by the supervisory indicator *S*. This latter indicator has two windings, both of which are connected to battery. It does not therefore operate due to the loop from the subscriber's telephone during speaking conditions, but when the receiver is replaced an operate circuit for the supervisory indicator is completed from earth through the subscriber's bell, contacts *CS*1, the *A*-line and one coil of *S*. The second coil of *S* is provided primarily to match the impedance of the *A*- and *B*-lines to earth and does not form part of the signalling circuit. The two coils of *S* are so connected that they offer the maximum impedance to any currents circulating round the loop. The connexions are such, however, that any

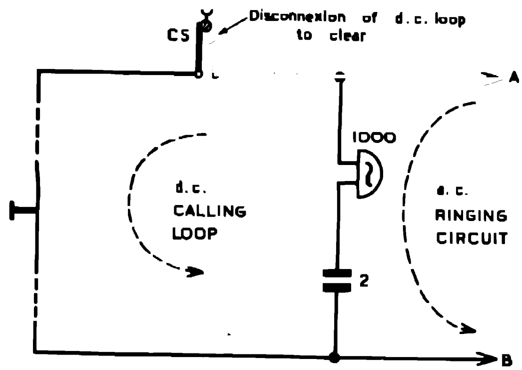


FIG. 192. BASIC SIGNALLING CIRCUITS OF C.B.S.2 AND C.B. TELEPHONES

direct currents in the windings of *S* due to a low insulation or earth fault on the line act differentially and so prevent false operation of the supervisory indicator.

When the connexion is established, the operator applies ringing current to the called subscriber's line over the *A*-wire by the operation of her cord circuit ringing key.

C.B.S. No. 2 System. The C.B.S. No. 2 system has now superseded the C.B.S. No. 1 system for all new work, and the few remaining C.B.S.1 exchanges are rapidly being converted either to

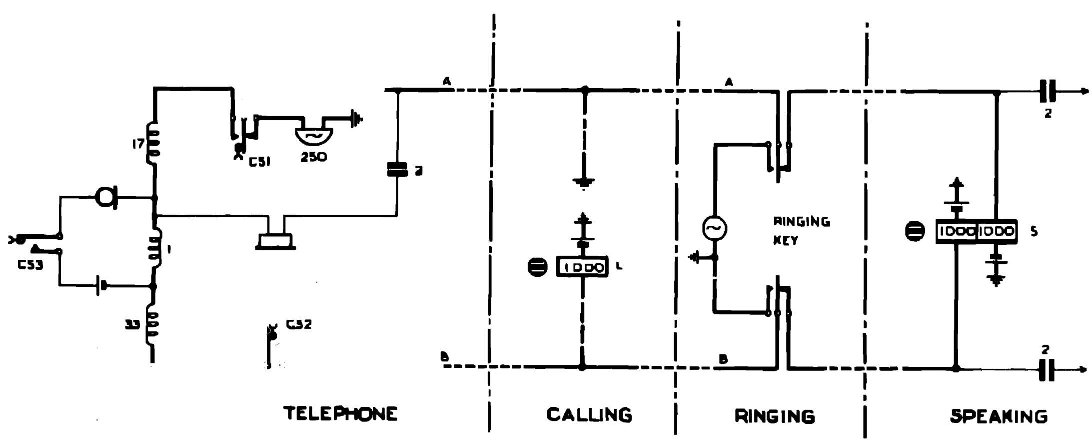


FIG. 191. CALLING, RINGING, AND SPEAKING CONDITIONS OF THE C.B.S. NO. 1. SYSTEM

C.B.S.2 or to automatic working. The elements of a C.B.S. No. 2 signalling circuit are shown in Fig. 192. Normally, the *A*- and *B*-wires are disconnected at the cradle switch contacts (*CS*), but an a.c. circuit for ringing current is provided by the magneto bell and 2 μF condenser in series. When the receiver is lifted, a d.c. loop is provided to the exchange and at the end of the call the breaking of this loop gives the clearing signal to the operator. indicator or relay is connected to battery and is applied to the *B*-wire, whilst the loop is completed by the application of a full earth on the *A*-wire (see Figs. 191 and 194). The earth connected calling indicator has possibly some advantage in that it is not liable to operation from low insulation or earth faults on the line. On the other hand, the very absence of this indication prevents such faults from being brought to notice.

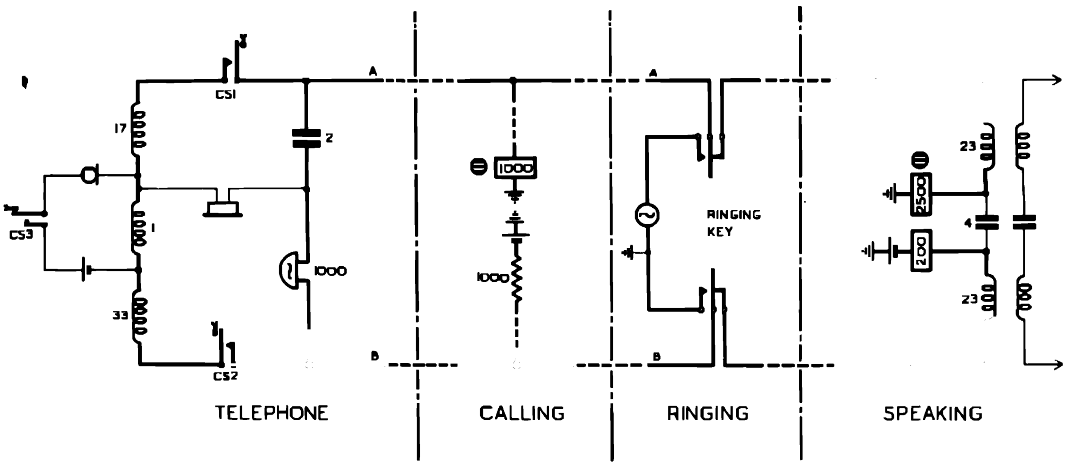


FIG. 193. CALLING, RINGING, AND SPEAKING CONDITIONS OF THE C.B.S. No. 2 SYSTEM

The more detailed connexions are shown in Fig. 193. The telephone circuit is substantially similar to that used in the magneto and C.B.S. No. 1 systems, except for the connexions of the bell and condenser. When the subscriber lifts his receiver, the resulting loop operates the 1000 Ω calling indicator on the *A*-line to a battery supplied via the non-inductive resistance in the *B*-wire. This arrangement is the reverse of the usual connexions of a loop calling circuit. In most systems the calling

When an answering plug is placed into the line jack of a calling subscriber, the calling indicator and its battery feed are cut out and are replaced by a transmission bridge in the cord circuit which includes a 2500 Ω indicator in the *A*-wire and 200 Ω impedance coil in the *B*-line circuit. It will be noted that, under both the calling and speaking conditions, the signalling circuits are of very high d.c. resistance in order to economize in current consumption. It would be preferable on transmission

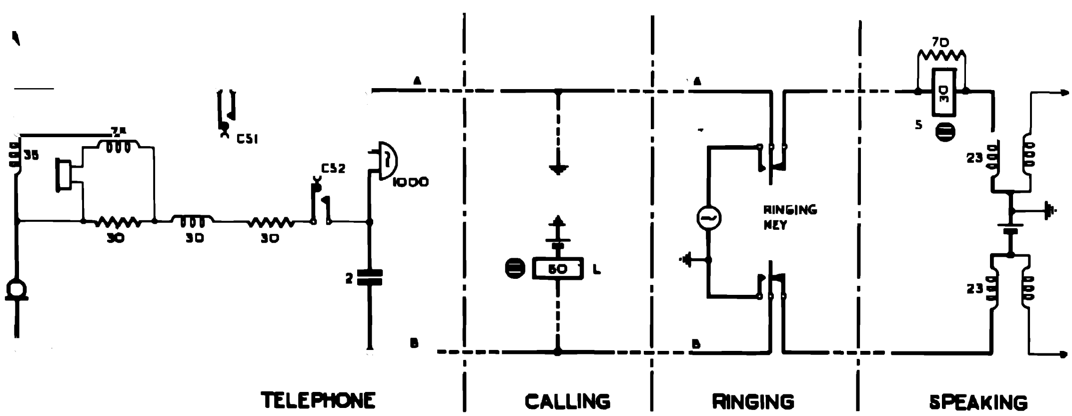


FIG. 194. CALLING, RINGING, AND SPEAKING CONDITIONS OF THE C.B. SYSTEM

grounds to equalize the resistance of the supervisory indicator and the retard coils to obtain a good balance in the impedance of the A- and B-lines to earth. This would involve a retard coil in the B-line circuit of between 1000 and 2000 Ω. Unfortunately the same cord circuit is required to provide the signalling conditions on junctions, and the presence of a high resistance in series with the battery on the B-line would seriously reduce the junction limits over which automatic signalling is possible. It is therefore usual to concentrate the supervisory circuit resistance in the indicator connected to the A-wire and to compensate for the unbalance so introduced by including a repeating coil transmission bridge with 4 μF equalizing condensers.

The ringing circuit is substantially similar to that of the C.B.S. No. 1 and magneto systems already considered.

The Central Battery System. The Central Battery (abbreviated C.B.) system is now recognized as the most satisfactory system of manual switching. The only advantage of the C.B.S. No. 2 system is the low power consumption, but the rapid extension of rural electrification in recent years and the development of static rectifier charging plants have made the introduction of full central battery working practicable even at small and isolated exchanges.

The signalling elements of the C.B. system are the same as those of the C.B.S. No. 2 system (Fig. 192) except that the direct signalling current is much greater and is used also for the energization of the subscriber's transmitter. Typical calling, clearing, and ringing conditions are illustrated in Fig. 194. The instrument circuit includes the anti-sidetone transmission circuit already considered, with a 1000 Ω magneto bell and a 2 μF condenser across the speaking pair. Cradle switch contacts ($CS1$) are provided to close the d.c. loop when the receiver is lifted from the rest. A further pair of cradle switch contacts ($CS2$) are included in the receiver circuit to prevent the passage of direct current via the bell. The calling indicator (L) is connected to the B-line, and the loop is completed by an earth applied at the exchange to the A-line. When the calling condition is answered, the indicator and earth are removed from the speaking pair and a C.B. transmission bridge is provided in the cord circuit. This transmission bridge can be either of the repeating coil or impedance coil type. In the former case a separate supervisory indicator is provided in series with the repeating coil and the A-line. With the impedance coil type of bridge the impedance element connected to the A-wire serves as the supervisory indicator. It should be noted that in either system the supervisory indicator is operated whilst the call is in progress and is released when the subscriber hangs up. If it is desired to convert from this negative clearing feature to a positive clearing signal, it is necessary to replace the supervisory indicator in the speaking circuit by a relay and to provide break contacts on the relay, which in turn can energize a supervisory indicator at the end of the call.

Signalling for Automatic Switching. So far we have considered the various methods of passing a simple calling signal from a subscriber to his local manual exchange. If now the required exchange employs some method of automatic or machine switching, the signalling system must not only give the usual calling facilities, but must also indicate to the automatic equipment the number of the line required. In some of the very earliest automatic systems, additional wires were provided between each telephone and the exchange and a telegraph type key associated with each signalling wire was used to "tap out" the required number by sending out earth pulses along the signalling wires. At first a separate signalling wire and key were provided for each digit, but later one signalling wire on which each digit was tapped out in turn was made to suffice. Even then the additional wire per subscriber rendered automatic selection uneconomical, and it was soon realized that the only solution was in the use of the existing speaking pair for all signalling.

With this economic requirement in view there are only two methods of signalling of any practical value:

(*a*) The application for each digit of a train of earths on one or both wires.

(*b*) The interruption of the normal subscriber's loop by a train of disconnexions for each digit.

The former method incurs the usual difficulties of an earth signalling circuit, e.g. possible high earth resistance, difference of earth potentials, extra cost of wiring, etc., and it is never used except in abnormal circumstances when the disconnexion method cannot for some reason be employed.

Impulsing Terms. In all present-day automatic systems signalling by means of interruptions in the loop circuit is the normal method. If, say, the digit 7 is to be transmitted, the current in the line is interrupted seven times in rapid succession. Each of the seven interruptions is called a *break impulse*, or more simply an *impulse*, and the whole signal of seven impulses is known as an *impulse train.* The process of sending out impulse signals is known as *impulsing.* The current during an impulse train varies as in Fig. 195, each break of the circuit being followed by a short make period. The time between

the corresponding points of two successive impulses is referred to as an *impulse period* and, as will be seen later, the length of this impulse period and the ratio of the make and break portions are important factors in the design of an automatic telephone system. The length of the impulse period is not in practice often stated, but can be calculated from a exchange both before the first train of impulses is received and between each successive train of impulses. Hence, a period of *minimum pause* before impulsing and between impulse trains must be ensured by the mechanical design of the impulse sending mechanism. A minimum *inter-digit pause* of some 400 to 500 msec is required between

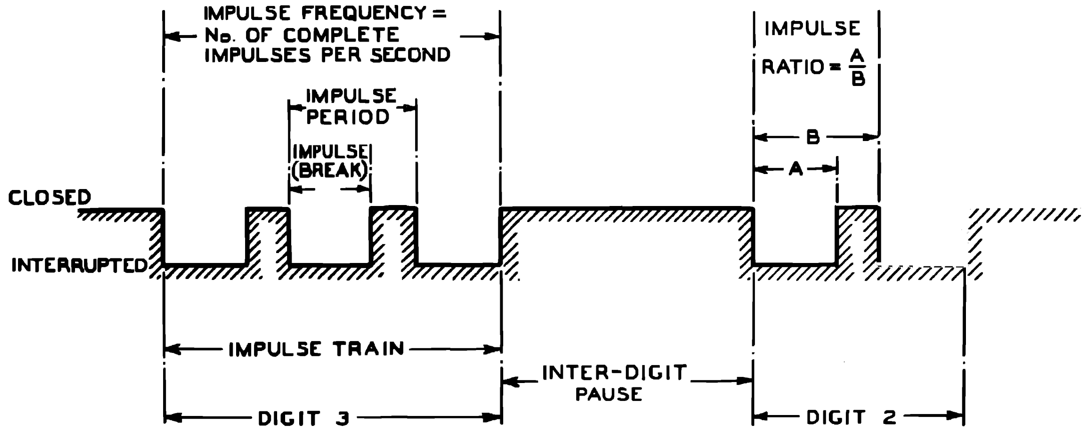


FIG. 195. ILLUSTRATING THE TERMS USED IN IMPULSING

knowledge of the *impulse frequency*, i.e. the number of impulse periods (or impulses) per second. Similarly the relative lengths of the make and break portions of an impulse period are usually expressed by the *impulse ratio* which is the ratio of any impulse (normally the break) to the total impulse period. Modern automatic exchange equipment is designed to work with a dial impulse impulse trains. Approximately half of this time is taken up by the telephone subscriber in operating the instrument, and the impulse sending mechanism itself is mechanically arranged to introduce a period of some 200 msec before each train of impulses.

Loop Impulsing. The principle of *loop impulsing* (or more correctly *loop disconnect impulsing*)

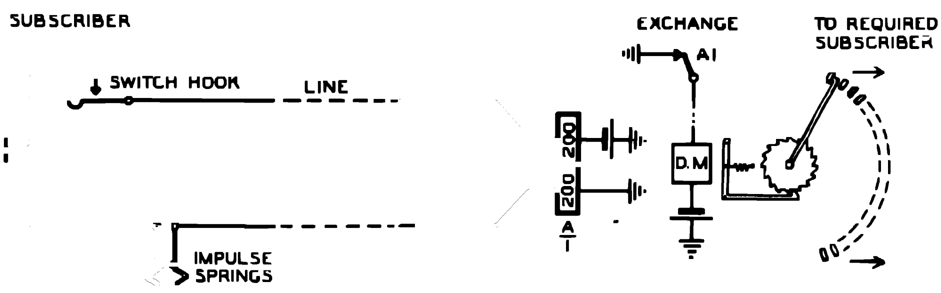


FIG. 196. PRINCIPLE OF LOOP IMPULSING

frequency of 10 impulses per second with a permissible range of from 7 to 12 I.P.S. The standard impulse ratio is 66 per cent break with a tolerance of from 63 per cent to 72 per cent. Accurate adjustment of the impulse sending mechanism is necessary to maintain these fairly close limits.

As will be seen later, various hunting and switching operations are necessary at an automatic as applied to a subscriber signalling to an automatic exchange is illustrated in Fig. 196. When the subscriber lifts his receiver, the two lines are looped and the resulting line current prepares the exchange equipment to receive the call. In series with one of the lines is a pair of *impulse springs*, which, in the normal position, are in contact. The impulse springs form part of a mechanical assembly

designed so that when operated by the subscriber the required number of impulses can be sent out. The impulse accepting relay (*A*) at the exchange is released for a short time during each break impulse and at its local contacts gives one pulse of current to the electromagnet of a mechanism for each impulse received. The electromagnet in turn operates through a ratchet and pawl system to step the fingers or *wipers* of the selecting mechanism to the contacts corresponding to the required line. This principle is, of course, considerably elaborated in practice but the reader need not at this stage be concerned about the detailed circuit arrangements at an automatic exchange.

The Dial. The impulse sending device of all modern automatic systems is a mechanism controlled by a rotatable disc provided with holes or slots corresponding to the numerals, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0. Owing to this method of control and due to the general appearance of the mechanism, it is known universally as a *dial* and the process of impulsing is usually described as *dialling*. In view of the extensive application of the dial to both subscriber's apparatus and in manual exchanges it is perhaps desirable to consider at this stage the detailed construction and method of operation of this important component.

The standard dial used in the Post Office (Dial Auto No. 10) consists of a circular metal *finger-plate* with ten finger holes, and rigidly fixed to a central spindle. The finger holes are equally spaced round two-thirds of the outer annular ring of the plate (Fig. 197). *The number ring*, of white vitreous enamel on copper, is fixed to the case behind the finger-plate in such a position that when the plate is normal, the digits 1, 2, 3 . . . 0 are exposed through the finger holes. In some cases, where the subscriber is required to dial the exchange name as well as the number, letters, in addition to the numerals, are shown on the number ring. To avoid confusion the letters are enamelled in black and the figures in red. Bent over the finger-plate in a position adjacent to the digit 0 is a fixed *finger stop*. The central portion of the finger-plate accommodates a label giving instructions in the use of the dial, and bearing the telephone number of the instrument with which the dial is associated. The label is protected by a transparent disc, and both are held in position by a spring securing ring.

The dial has an overall diameter $3\frac{1}{8}$ in. and an overall depth of $1\frac{1}{8}$ in., and there are no exposed screw heads to invite tampering by the subscriber or other unauthorized person. The diameter of the finger holes and the distance between the finger-plate and the number ring are so arranged that, whilst there is no difficulty in seeing the numerals, the finger only enters the hole sufficiently far to ensure easy dialling, and does not rub against the number ring behind. The finger-plate is constructed of bright stainless steel in order to

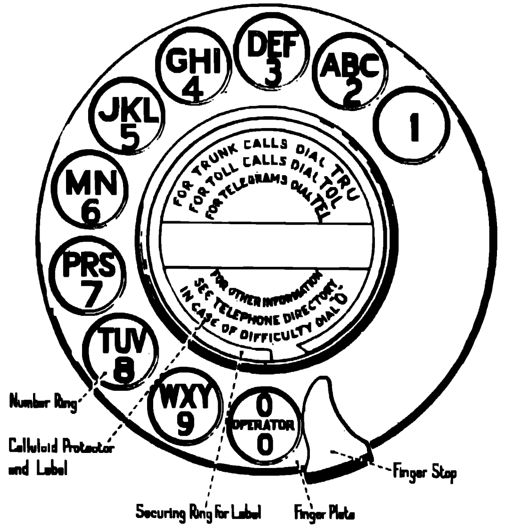


FIG. 197. FRONT VIEW OF DIAL
Dial No. 10LA.

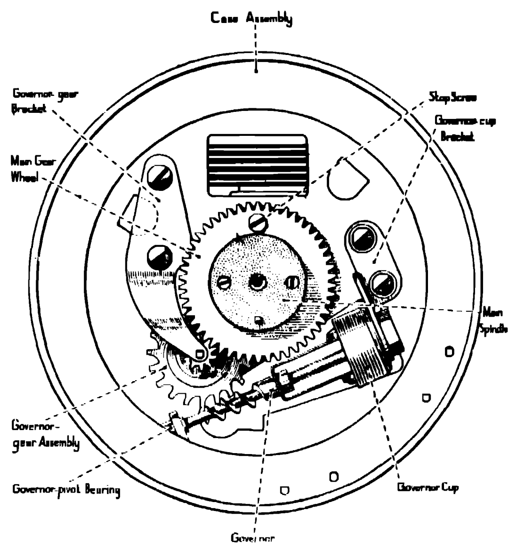


FIG. 198. DIAL WITH FINGER-PLATE AND NUMBER RING REMOVED

harmonize with telephones of all colours and to give a finish which does not deteriorate with use.

Fig. 198 is a view of the front of the dial with the finger-plate and number ring removed. The main *spring box*, containing a flat clock spring, is fixed

to the case, and one end of the main spring is secured to the box whilst the other end is fixed to the central spindle. The *stop screw* serves to keep the spring in a partially wound condition, and also to stop the rotation of the finger-plate and mechanism on their return to the normal position. The *main gear wheel* is securely fixed to the central spindle and drives the *governor gear* which is of the worm and worm wheel type so as to provide extreme sensitivity to variations of speed. A small helical spring is contained in the governor

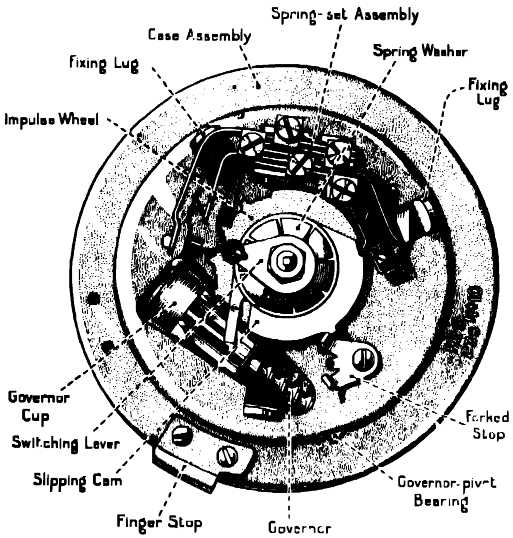


FIG. 199. REAR VIEW OF DIAL

gear and forms the coupling between the small gear wheel and the worm wheel. The *governor* consists of two wings, each having a small weight at the free end. The weights are arranged to rub over the inner surface of the governor cup when they move outwards under the influence of the centrifugal force set up by rotation. The friction so generated serves to limit the speed of the governor, and consequently the speed at which the mechanism of the dial rotates.

A view of the rear of the dial mechanism is given in Fig. 199. The *impulse wheel* is rigidly fixed to the central spindle and has ten slots in its periphery spaced at the same angular intervals as the holes in the finger-plate. The switching lever is fixed to the central spindle, and between it and the impulse wheel a *slipping cam* and assembly of washers are loosely fixed on the spindle, as shown in Fig. 200. There are two groups of contact springs, the *impulsing springs* and the switching or *off-normal springs*. The off-normal springs are provided to give various switching facilities when the dial is moved from rest. In the normal position of the dial, the switching springs are held apart by the *switching lever*, and the impulse springs are held closed by the *impulsing lever* which rides on the outer edge of the impulse wheel.

When the finger-plate is moved away from its normal position (Fig. 201), the switching lever

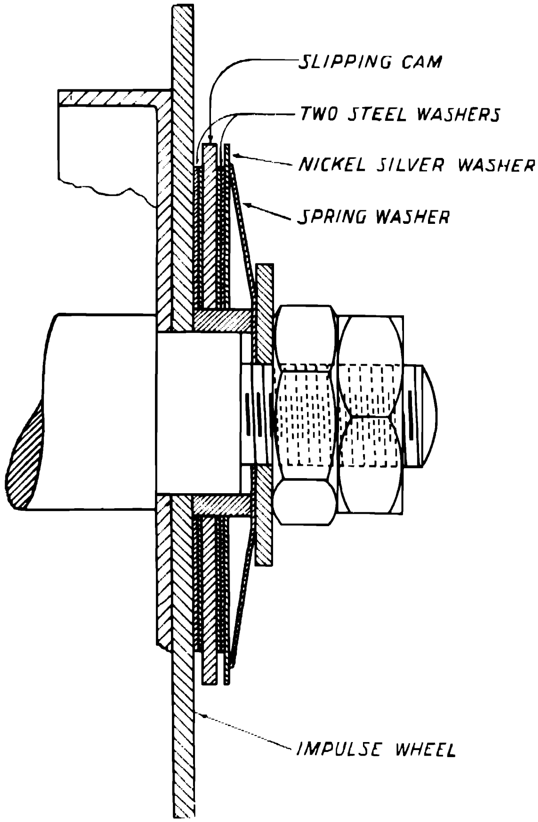


FIG. 200. ENLARGED CROSS-SECTION OF SLIPPING CAM

moves away from the switching springs, so allowing the two pairs of springs to make contact. As the finger-plate moves round, the helical spring in the governor gear tends to unwind and prevents excessive rotation of the governor worm, which would otherwise drive the governor and retard the movement of the finger-plate. The slipping cam is held to the impulse wheel by the pressure of the spring washer, and rotates until the projection on the cam strikes the *forked stop*. Further rotation of the cam is now prevented, and the continued rotation of the finger-plate causes the rotation of the main gear wheel, impulse wheel, and switching lever only. When the clockwise rotation of the finger-plate is completed, a number of slots in the

impulse wheel corresponding to the digit dialled have been exposed by rotation past the *impulsing recess* in the slipping cam. As the impulse lever

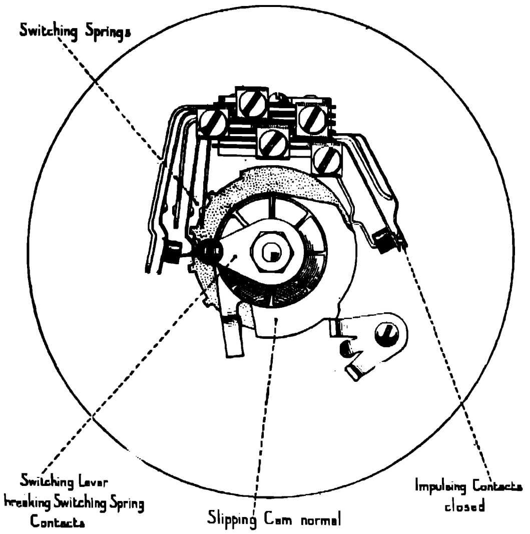


FIG. 201. NORMAL POSITIONS OF IMPULSE WHEEL, SLIPPING CAM, AND CONTACT SPRINGS

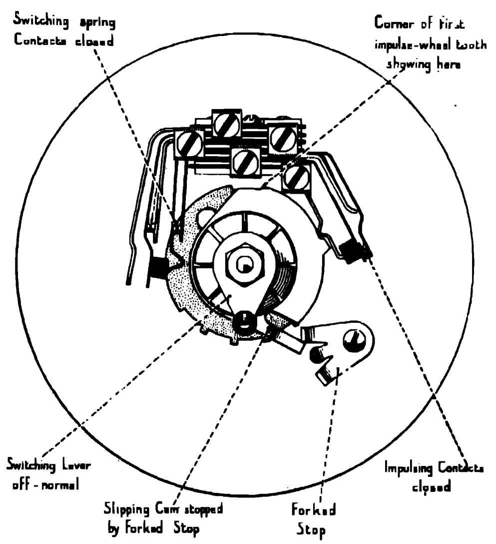


FIG. 202. POSITION OF IMPULSE WHEEL, ETC., JUST PRIOR TO THE REMOVAL OF THE FINGER AFTER DIALLING 1

rides on the periphery of the slipping cam, it is not affected by the movement of the impulse wheel which takes place during the process of setting up a digit prior to its transmission.

Fig. 202 shows the state of the dial mechanism at the time immediately prior to the removal of the finger from the finger-plate during the dialling of the digit 1. The governor has been omitted from the figure to simplify the drawing. Upon the removal of the finger, the finger-plate, main gear wheel, impulse wheel, and switching lever return to normal, driven by the main spring. The slipping cam also rotates due to the pressure exerted by the spring washer which clamps it to the impulse wheel. The helical spring in the governor gear now tends to wind up, thereby causing the governor

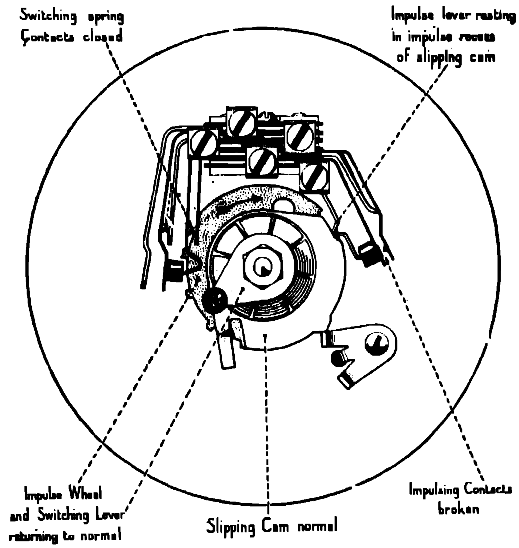


FIG. 203. POSITION OF IMPULSE WHEEL, ETC., DURING TRANSMISSION OF IMPULSE

to rotate at its maximum speed; the speed at which the dial mechanism returns to normal is so maintained constant. The impulse lever rides on the edge of the slipping cam until the small projection on the cam strikes the forked stop. The slipping cam is now in its normal position and the slots in the impulse wheel are exposed beneath the impulse lever, in the impulsing recess of the slipping cam. The lever now falls down into the first slot, so permitting the moving spring of the impulsing springs to break contact with the fixed spring. This position is shown in Fig. 203. The continued rotation of the impulse wheel causes the impulsing contacts to be broken and made the number of times corresponding to the digit dialled.

When the impulsing contacts close at the end of the last break period, the switching lever opens the switching springs as the finger-plate comes to rest against the stop screw. The helical spring in the governor gear now unwinds and allows the governor to over-run slightly, so preventing any shock to the

governor mechanism which would otherwise be given by the abrupt stop.

From the foregoing description, it will be seen that a short period elapses between the removal of the finger from the finger-plate and the commencement of the break period of the first impulse, during which the slots on the impulse wheel are masked from the impulsing lever by the slipping cam. This period is nominally 200 msec, and is

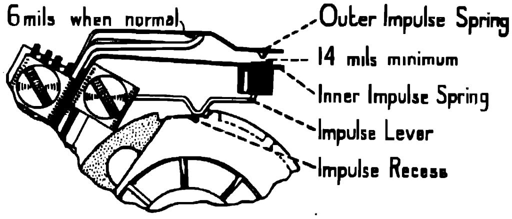


Fig. 204. Adjustments of Dial Impulse Springs

known as the *lost motion period* or the period of minimum pause. The lost motion period, together with the minimum time required to rotate the dial to the finger stop, provides the necessary inter-digit pause to enable the automatic switching equipment to carry out certain automatic actions between impulse trains.

Dial Adjustments. The somewhat critical performance limits and the intricate nature of the dial mechanism makes it inadvisable to do other than very simple repairs *in situ*. Generally, faulty dials are changed by the faultsman and repairs are carried out at a central depot by specialized staff.

Apart from the more obvious checks of mechanical adjustment such as the correct running of the governor, tension of the cup spring, etc., possibly the most important adjustment is that of the impulse spring set. Correct spacing of the contacts is necessary to obtain the specified impulse ratio (66%B) whilst a good contact pressure (20–35 g) ensures reliability of operation (Fig. 204). The pressure of the impulse lever against the impulse wheel must not be excessive (5–15 g specified) or it will make the return motion of the dial erratic. Contact pressure of the switching springs is ensured by adjusting the lever springs so that there is a distinct "follow" of the contact springs when the dial is moved off-normal. The outer springs (x) are also adjusted to make before the inner pair to prevent clicks in the subscriber's receiver when the dial is pulled off-normal (Fig. 205).

It is important that the friction of the slipping cam shall be sufficient to give reliable operation, but not so great that the return movement of the dial is retarded. It is therefore specified that the cam shall not slip with a tangential pressure of 60 g applied at the smaller stop projection; but shall slip when this pressure is increased to 90 g. Speed regulation of the dial is obtained by adjusting the position of the governor springs. The nominal speed is 10 I.P.S. with a permissible variation of from 9 to 11 I.P.S. To increase the speed, the governor springs are bent inwards and vice versa.

Call Office Dial. Call office circuits on automatic systems are arranged so that the insertion of coins is necessary before a number can be dialled. This introduces difficulties in an emergency if the caller does not have the requisite coins. Arrangements are therefore made to enable a caller to dial "0" without inserting money. In certain areas, a special code number (usually 999) has been introduced to facilitate the rapid handling of emergency calls (police, fire, etc.). In all such areas the call office circuit must enable the emergency number to be dialled without the prior insertion of coins.

The normal call office circuit applies a short circuit to the impulse springs until the requisite coins have been deposited. To differentiate on "0" and "999" calls, a special dial (P.O. No. 11) is provided which removes the short circuit on any predetermined digit (usually 9 or 0). A cam (Fig. 206) fixed at the end of the dial spindle normally

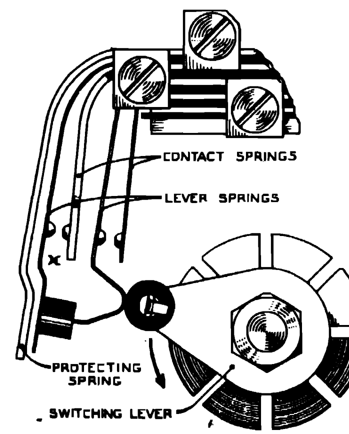


Fig. 205. Dial Off-normal Springs

holds a pair of auxiliary springs in contact. The cam has ten holes into which screws can be inserted as required. The arrangement is such that when a screw is inserted in, say, hole 9, the switching lever strikes the screw when the dial is rotated to the ninth digit hole and the movement of the cam allows the auxiliary contacts to break the short circuit across the impulsing springs. When the dial restores to normal the switchinglever again

ngages the auxiliary cam screw of digit 0 to reset he mechanism.

The Trigger Dial. Experience has shown that he slipping cam of the standard Post Office Dial s the cause of a considerable number of service faults. Excess of lubricant between the impulse wheel and the slipping cam or inadequate pressure results in the cam slipping during the forward motion of the mechanism, whilst, on the other hand, there is a tendency for the oil to congeal at low temperatures with the consequent drag on the return motion of the dial. Figs. 207 and 208

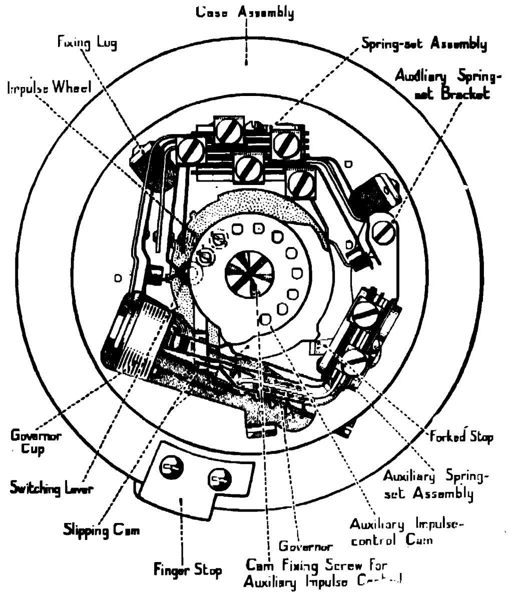


FIG. 206. REAR VIEW OF CALL OFFICE DIAL

illustrate a new type of dial in which the slipping cam has been eliminated. Apart from the elimination of the somewhat troublesome slipping cam mechanism, the new dial materially reduces the number of piece parts.

The impulsing mechanism is in the form of an articulated trigger which is so arranged to prevent transmission of impulses during the forward motion of the dial and to give an adequate inter-digit pause before each impulse train. The trigger portion (*D*, Fig. 209) is constructed of stainless steel and is fitted to a small pivoted bracket (*E*) screwed to the dial case. When the dial is wound up the trigger is caused, by means of the impulse wheel (*C*) and a tensioned leaf spring (*F*), to turn over in preparation for impulsing. When the finger-plate is released, the trigger agains turns over and the lower end of it (*D*) engages the segments of the impulsing cam according to the digit dialled, whilst the insulated roller at the end of *D* engages the impulse springs. The inter-digit pause of approximately 230 msec is provided in the time occupied from the release of the finger-plate and the turn over of the trigger

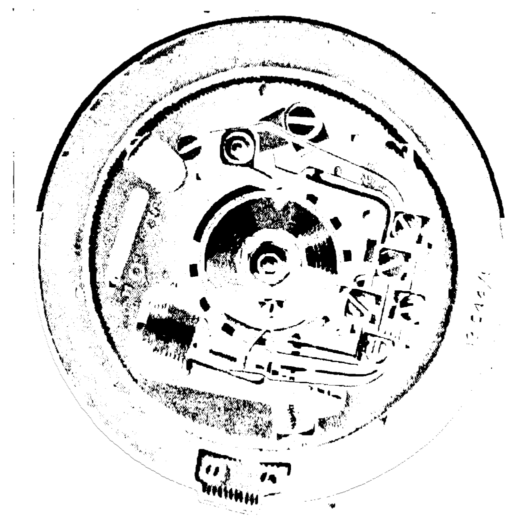


FIG. 207. REAR VIEW OF TRIGGER DIAL

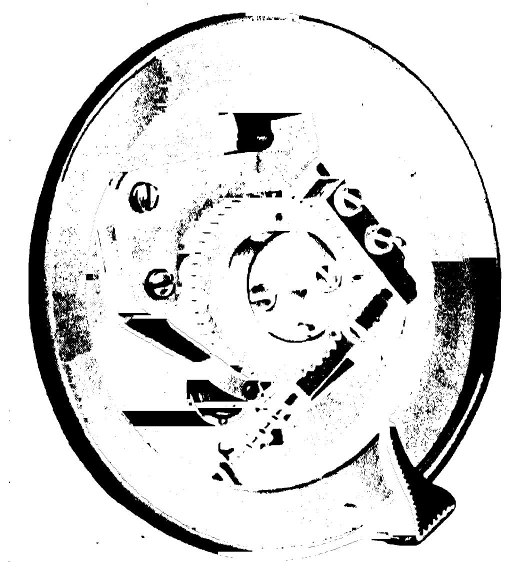
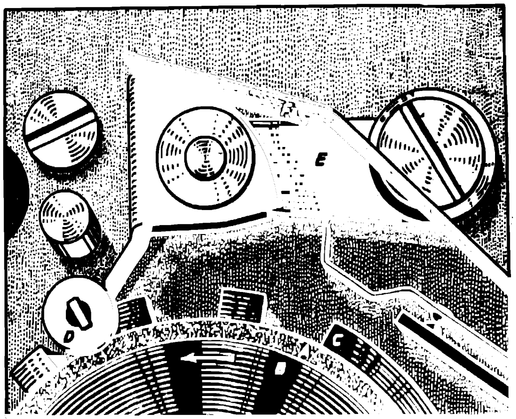
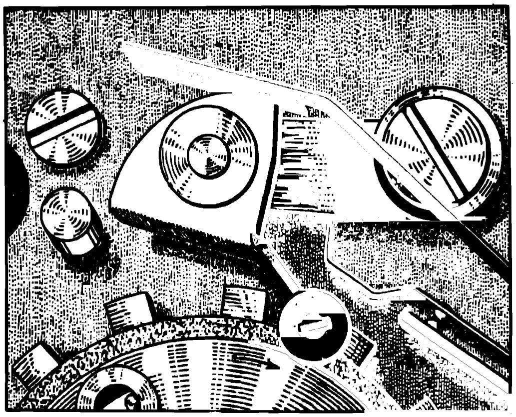


FIG. 208. FRONT VIEW OF TRIGGER DIAL
With finger-plate and number disc removed.

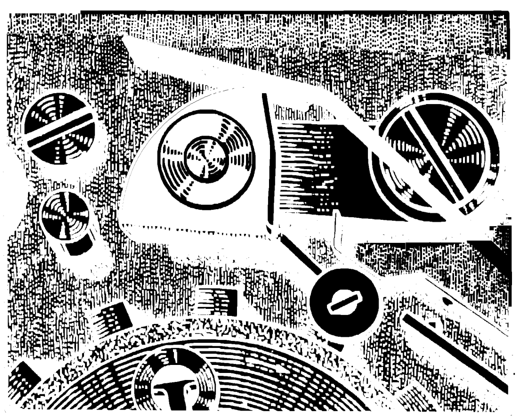
to the commencement of the first break impulse. Considerable attention has been paid to lubrication. A specially selected white felt washer (*A*) is located



(a) Dial wound, showing trigger in position prior to commencement of inter-digit pause.



(b) Showing toggle turned over and almost at end of inter-digit pause.



(c) End of inter-digit pause and trigger giving first impulse.

FIG. 209. IMPULSE MECHANISM OF THE TRIGGER DIAL

between the nickel-silver cone-shaped washer (B and the impulsing cam (C). Having first been immersed in a first grade mineral clock oil and the surplus oil squeezed out, the felt washer provides a means by which the impulsing trigger *D* and the impulse wheel teeth are kept lubricated. The felt washer also forms a buffer against which the impulse trigger impinges when it falls into the recess of the impulse cam, thereby reducing the noise of operation to a minimum. Lubrication of the trigger mechanism is similarly provided by two oiled felt washers mounted on the phosphor-bronze pivot. Stops are provided to prevent excessive movement of the impulsing trigger to guard against distortion of the trigger spring and to prevent backlash of the trigger.

A number of other minor improvements have been incorporated in the new dial. The governor star wheel is now made from a special type of fine fabric bakelite. This material reduces noise and is claimed to minimize "stalling" faults and noisy operation. Arrangements have also been made so that the main spring can be released from the back of the dial instead of from the front as in the standard dial. This is accomplished by partially withdrawing a screw which holds in position a spring steel detent, a projection of which engages the stop on the under-side of the main gear wheel. The front of the dial case has also been amended to prevent the entry of dust through the main spindle hole. Felt washers have also been introduced directly behind the number-plate to minimize mechanical resonance during dialling.

Automatic Systems. Subscribers' instrument circuits in an automatic system are required to give the following signalling facilities:

(*a*) A d.c. loop to call.

(*b*) Interruptions of the d.c. loop during dialling.

(*c*) A disconnexion of the d.c. loop to clear.

(*d*) A condensered bell circuit for the ringing signal.

In the early days of automatic telephony, the ordinary C.B. instrument circuit was adapted for automatic working by inserting the impulse springs of the dial in one or other of the outgoing lines. This simple arrangement suffers from several important defects:

(*a*) Loud clicks are heard in the receiver each time the line current is started or stopped at the impulsing contacts.

(*b*) The transmitter and induction coil winding resistances are included in the impulsing circuit.

(*c*) There is a tendency for bell tinkling to occur.

(*d*) The voltage induced in the line at the moment

f break of the dial contacts is very high indeed due primarily to the high inductance of the mpulsing relay at the exchange). The high voltage roduced during dialling interferes badly with djacent speech circuits, produces sparking at the ial interrupter contacts, and in some cases results n a breakdown of the insulation of the wiring.

The undesirable noise in the receiver during dialling was eliminated by the provision of dial off-normal contacts which were arranged to short-circuit the receiver for so long as the dial remained away from its normal position. At the same time further off-normal contacts were provided to short-circuit the transmitter. The transmitter resistance itself is not great and does not have a very appreciable effect on impulsing, but it was considered advisable to eliminate the transmitter from the impulsing circuit as a matter of policy and to provide for any possible changes in transmitter design. The sparking at the dial impulse contacts and the high induced voltage on the line at the moment of break were very considerably reduced by rearranging the position of the impulse springs so that a quench circuit was formed by the instrument condenser and the resistance of the induction coil secondary windings. Difficulties of bell tinkling were, however, still experienced due to the change of potential across the bell and condenser circuit as the lines were alternately looped and broken by the dial impulse contacts. In some systems the difficulty was overcome by the provision of a bias spring to the magneto bell, but this remedy merely introduced maintenance difficulties and was not always completely successful.

The signalling and impulsing circuits of a modern automatic instrument are shown diagrammatically in Fig. 210. The a.c. ringing circuit is as usual a 1000 Ω bell and 2 μF condenser in series across the lines. When the receiver is lifted from the rest a d.c. calling loop is provided by cradle switch contacts (*CS*), which also give the clearing disconnexion at the end of a call. Two pairs of dial

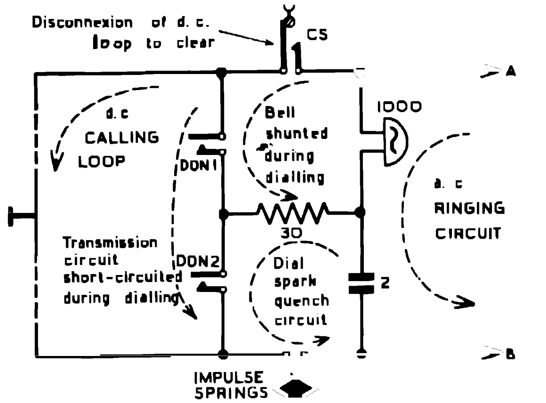


FIG. 210. BASIC SIGNALLING CIRCUITS OF AUTOMATIC TELEPHONE

off-normal contacts are fitted and a 30 Ω non-inductive resistance is included (for convenience) in the induction coil. The circuit is so arranged that during impulsing the whole of the transmission part of the telephone is short-circuited by the dial off-normal contacts. The 30 Ω resistor and the 2 μF condenser are connected across the impulse springs of the dial to provide a spark quench circuit which effectively reduces the voltage generated when the circuit is broken. At the same time the magneto bell is shunted by the 30 Ω resistor which avoids any possibility of tinkling during dialling.

The more detailed circuit of the automatic type instrument and the conditions at the exchange during calling, ringing, and speaking are illustrated

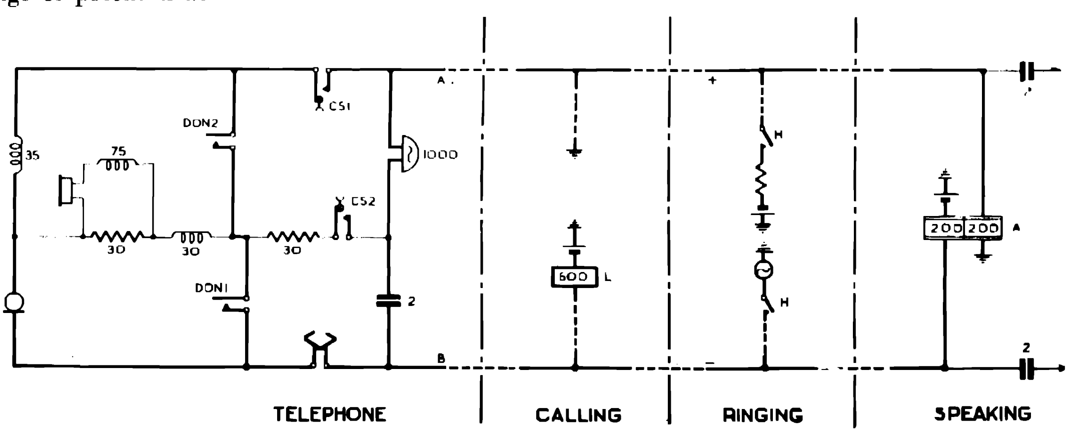


FIG. 211. CALLING, RINGING, AND SPEAKING CONDITIONS OF AN AUTOMATIC SYSTEM

in Fig. 211. The instrument circuit is similar to the C.B. telephone already described, but with the addition of the dial impulse springs and the two sets of dial off-normal contacts. It is usual, in fact, to utilize the same instrument for both C.B. and automatic working, but to provide the dial only in the latter circumstances. When the receiver is lifted from the rest the calling loop operates relay *L* at the exchange and, after dialling and when the connexion is finally established, the transmission bridge (usually of the condenser impedance type) is connected to the speaking pair to provide the necessary transmitter energizing current. At the end of the call the disconnexion of the d.c. loop releases the supervisory relay *A* in the transmission bridge, which in turn allows the whole switching train to restore to normal. The ringing circuit is arranged so that earthed ringing current is applied to the negative or *B*-wire whilst a ringing return battery is applied to the *A*-line. The ringing circuit at the exchange is so designed that the completion of the d.c. loop when the called subscriber replies operates a ring-trip relay to disconnect the ringing current.

Party Lines. Party lines, in which two or more subscribers' stations are connected to the same line, were common in the early days of telephony. In rural areas the joint use of one pair of wires by several subscribers is very attractive on economic grounds but, with the advent of automatic switching, party lines have in this country been largely eliminated. There are two main types of party line, viz. *two-party lines* and *rural party lines.* The two-party line, as its name implies, provides for two subscribers on the same pair of wires, whereas up to twelve stations may be provided on a rural party line. Party lines do not normally provide secrecy of conversation, but it is possible to minimize the disturbance of the various subscribers on the party line by the adoption of earthed ringing circuits instead of the more normal loop ringing conditions. On the two-party line, therefore, it is usual to arrange one of the bells on the *A*-line to earth and the bell of the second station on the *B*-line to earth. Thus, by reversing the connexions at the exchange it is possible to call one or other of the subscribers without disturbing the other. Similarly, on rural party lines it is usual to arrange the subscribers in two groups, i.e. X subscribers with bells connected on one line to earth and Y subscribers with the bells connected to the other line. Code ringing (i.e. 1, 2, 3, etc., rings) is used to call any particular station, but the Y subscribers are not disturbed if the call is for an X station.

On all party lines which use earthed ringing circuits, it is very important to balance the impedance of each line to earth during speaking conditions. Thus, in a rural party line of, say, ten stations, five of these stations should have their bells connected to one line and the remaining five to the other line. Hence, when one station is speaking, there will be four earthed bells on one speech conductor and five on the other. It would not be permissible to connect, say, six X subscribers and one Y subscriber on a given party line owing to the large out of balance resulting from the earthed bells. It is also usual to include a condenser in each bell circuit of a party line to isolate the lines from a d.c. point of view and to improve the transmission balance.

With manual switching, no special signal is required from a party line subscriber to the operator. The operator can obtain the number of the subscriber by direct inquiry on receipt of a call. On automatic systems, however, where the metering of calls is automatic, party lines necessitate some form of meter discrimination circuit at the exchange, unless both subscribers can agree to a common account for telephone charges. The complications introduced for differentiating on originated calls have been largely responsible for the elimination of party lines in Great Britain. A number of schemes have been designed and have worked more or less satisfactorily. In one scheme the circuit is arranged so that one subscriber on a two-party line sends a fleeting earth to the exchange as he lifts his receiver. This fleeting earth is made to lock up relays which later divert the metering condition to the correct subscriber's number. In another discrimination scheme one subscriber on a two-party line dials with normal loop impulses, but the second subscriber's circuit is arranged to furnish earth impulses to the exchange. As before the earth impulses are used to set up a meter discrimination equipment. For many years it has been the policy of the Post Office to discontinue party lines coincident with the conversion to automatic working. In cases where this was not practicable, arrangements were made to work the line on a manual basis direct to the automanual switchboard. This policy has been amended somewhat during the postwar years on account of the acute shortage of external line plant. Two-party lines, under the title of *shared service*, are being set up for new subscribers' lines in a number of exchange areas. Both subscribers have the use of a common pair of conductors between the distribution point and the exchange, and both are allocated different and distinctive exchange numbers. The arrangement does not provide for secrecy but independent ringing signals are obtained by the adoption of earthed ringing circuits instead of the usual loop ringing conditions to the subscriber.

EXERCISES VIII

1. Describe and explain the action of an ordinary trembler electric bell. Give reasons for the use of the various materials employed in its construction. (*Civil Service Probationary Inspectors Examination*, 1938.)

2. A magneto bell and a condenser are connected in series between ringing supply terminals at a telephone exchange. Explain fully, with the aid of a diagram, why the bell rings. (*C. & G. Telephony, Grade I*, 1941.)

3. A magneto bell and a condenser are connected in series across 75 V a.c. terminals, the frequency being 17 c/s. At this frequency the impedance of the bell is 2000 $\angle 45^\circ\ \Omega$ and the condenser may be regarded as a pure capacitance of 2 μF.

Calculate the current passing through the bell and condenser and the power factor of the combination. (*C. & G. Telephony, Grade II*, 1938.)

4. Explain, with the help of diagrams, the principle of the magneto generator.

In a circuit consisting of a magneto generator, an inductor and condenser, all connected in series what factors influence the strength of the current produced when the generator handle is turned?

Why is the current not directly proportional to the rate at which the handle is turned? (*C. & G. Telephony, Grade I*, 1940.)

5. Compare the calling, clearing, and ringing principles of the magneto, C.B.S.1 and C.B.S.2 systems. Illustrate your answer with simple sketches.

6. In the operation of a manual telephone system the following facilities are essential:

(*a*) Means for the subscriber to call the operator.

(*b*) Supply of current for the subscriber's transmitter.

(*c*) Supervisory signal to permit the operator to control the connexion.

Explain, with the aid of circuit diagrams, how these facilities are provided in the central battery system. (*C. & G. Telephony, Grade I*, 1940.)

7. Explain simply how an automatic subscriber transmits to the exchange details of the number required.

8. What is the function of the dial attached to the subscriber's apparatus used in automatic telephony? Give details of this device and explain its operation. (*Civil Service Probationary Inspectors Examination*, 1938.)

9. Explain the function of the slipping cam in an automatic telephone dial in relation to the stepping selectors. Describe, with the aid of a rough sketch, the mechanical operation of the cam. (*C. & G. Telephony, Grade I*, 1944.)

10. What do you understand by the following terms:

Impulse frequency. Impulse ratio.
Inter-digit pause. Impulse train.

11. Give a diagram of the transmission and signalling circuits of an automatic type telephone instrument. Explain how bell tinkling and clicks in the receiver are prevented during dialling. What are the reasons for the quench circuit across the impulse contacts?

CHAPTER IX

SUBSCRIBERS' APPARATUS

THE basic principles involved in the design of telephone instrument circuits have already been described in Chapters V and VIII. The various signalling arrangements and transmission principles are now shown together as complete telephone circuits. In a number of cases it will be seen that the practical connexions vary from the theoretical arrangement. Generally speaking these variations are introduced in order to:

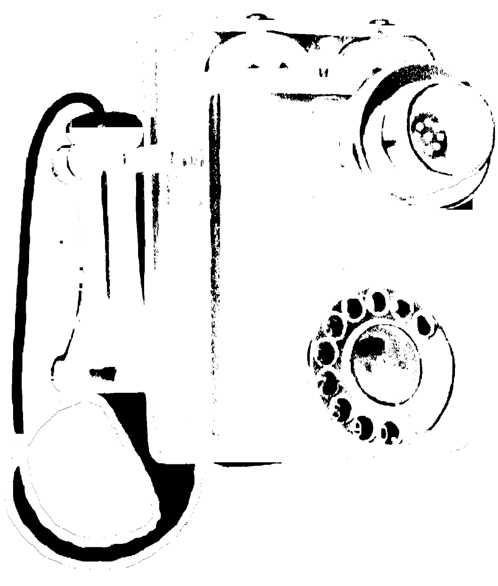


FIG. 212. WALL TYPE TELEPHONE FOR USE IN AUTOMATIC AREAS
Telephone No. 121.

(*a*) reduce the number of conductors in flexible cords (to minimize fault liability);

(*b*) make the instrument as adaptable as possible for different systems of signalling, and for extension working, etc.; and

(*c*) simplify the wiring of the instrument.

There are a large number of different types of instrument in service to-day and, whilst the current standard instruments are described in detail, it is possible to give only a brief description of the more common obsolescent items.

Wall Telephones. Figs. 212 and 213 show the general design and circuit details of a common type of wall instrument for use in automatic and (without the dial) in manual C.B. areas. The case is of polished hard-wood and contains the switch-hook, induction coil, condenser, and bell whilst the transmitter and dial are mounted on the front. The circuit is arranged for central battery transmission and the induction coil is of the simple two winding type which does not provide for sidetone reduction or accurate impedance matching of the receiver. The magneto bell circuit is condensered, whilst the lifting of the receiver provides a d.c. signalling loop in the usual way. The 2 μF condenser and the

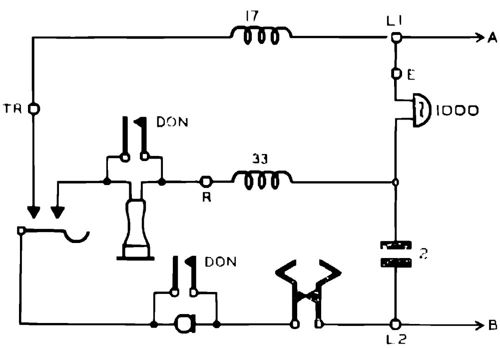


FIG. 213. CIRCUIT OF AUTOMATIC TYPE WALL TELEPHONE
Telephone No. 121.

33 Ω winding of the induction coil in series form a spark quench circuit for the dial impulse springs. Off-normal contacts of the dial short circuit the transmitter and receiver during dialling. In addition to the two line terminals, three additional connexions are brought out to tags marked TR, R, and E. The TR and R tags in conjunction with the L2 terminal enable a second simple telephone without induction coil or bell to be placed in parallel with the instrument. Similarly, an extension bell can be added in series with the instrument bell by removing the strap between L1 and E. This facility also enables the instrument bell to be connected to earth in special circumstances, e.g. party line working.

Figs. 214 and 215 shows the equivalent local battery instrument which can be used in C.B.S. Nos. 1 and 2 or in magneto areas. The generator is, of course, only fitted in magneto areas and the bell

circuit is connected as required for the particular signalling system. In C.B.S. No. 1 areas the two bell coils are connected in parallel to give a total resistance of 250 Ω and terminal EB is disconnected from G and wired to earth.

Both the above telephones are now very little used for new work and have been largely superseded by hand-microphone type instruments.

Pillar or Pedestal Telephones. Until a few years ago the pillar (pedestal or candlestick) type of telephone was by far the most common instrument. The pillar telephone (Fig. 216) contains only the transmitter and receiver together with the switch-hook and the necessary terminals for a flexible cord. It is necessary, therefore, to provide a separate *bell set* to accommodate the magneto bell, condenser, and induction coil. The bell set is designed to screw on to a convenient wall, the side of a desk, or any other vertical surface which is a satisfactory position for the bell. The flexible cord from the instrument is terminated on a suitable connexion strip and the latter is connected to the bell set by permanent wiring. The lines to the exchange are wired directly to the bell set.

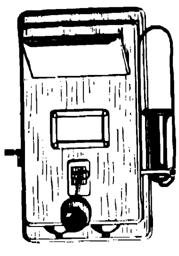


FIG. 214. LOCAL BATTERY WALL TELEPHONE
P.O. Telephone No. 11.

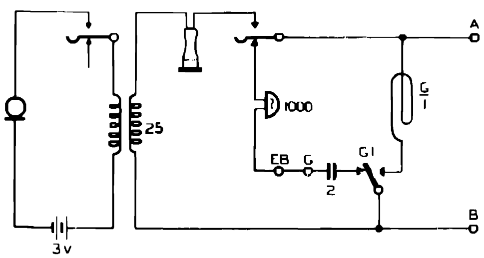


FIG. 215 LOCAL BATTERY WALL TELEPHONE CIRCUIT
Telephone No. 11.

Fig. 216 illustrates the apparatus for use in an automatic area. In C.B. areas the same pillar telephone is used with the dial replaced by a suitable dummy. In local battery areas the bell set is similar in appearance, but is, of course, wired for the particular system. When a pillar type of telephone is fitted in a magneto area a generator unit must be added. The generator is mounted in a small wooden box and is connected to the instrument terminal strip by a separate flexible cord.

Figs. 217 and 218 show the connexions for C.B. transmission and local battery transmission respectively. The local battery arrangement may be used in an automatic or C.B. area on lines which are of too high a resistance for C.B. transmission.



FIG. 216. PILLAR TYPE TELEPHONE FOR USE IN AUTOMATIC AREAS
Telephone No. 150 and Bell Set No. 1.

It will be noted that the C.B. instrument requires a three-way flexible cord, whilst the L.B. arrangement requires a four-way cord. In C.B.S. No. 1 areas terminal 8 of the pillar (Fig. 218) is connected

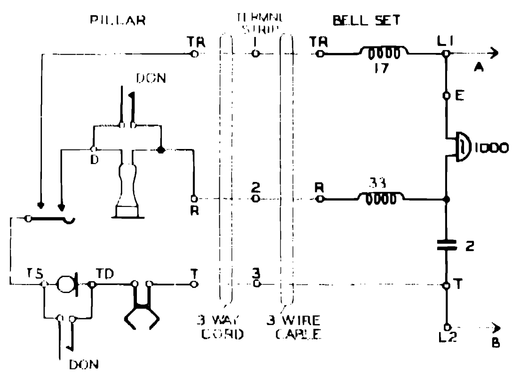


FIG. 217. CIRCUIT OF PILLAR TYPE TELEPHONE FOR AUTOMATIC SYSTEM
Telephone No. 150 and Bell Set No. 25.

to terminal 7 of the bell set, terminal *E* of the latter being disconnected from 1 and earthed. For magneto working the generator is connected to terminals 6, 7, and 8, so that the cut-out breaks 6 and 7 to prevent ringing the local bell when the generator handle is turned.

Hand Microtelephones. Separately mounted transmitters and receivers have been largely replaced in the more recent instruments by a combined unit known as a *hand microtelephone* or *handset*. The combined unit is much more convenient

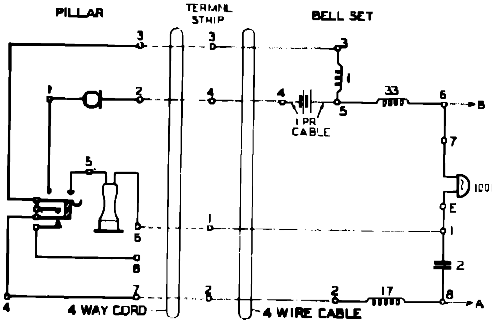


FIG. 218. CIRCUIT OF PILLAR TYPE TELEPHONE FOR LOCAL BATTERY AREA

Telephone No. 150LB and Bell Set No. 31.

to use than the older arrangement in which the transmitter is attached to the instrument. A more uniform standard of transmission efficiency is also obtainable with the hand microtelephone assembly, where the distance between the speaker's lips and the transmitter is predetermined by the design of the handset. With the old wall type of telephone in particular, there were numerous complaints of faint transmission due to the user not speaking close to the transmitter mouthpiece. On the other hand, the placing of a carbon transmitter in the handset is liable to introduce frying or other noises due to movement of the transmitter whilst in use. Particular care must, therefore, be taken in the design of the transmitter to ensure that it will work at almost any angle without frying.

Fig. 219 shows the standard hand microtelephone (abbrev.: H.M.T.) assembly. A three-way flexible cord connects the microtelephone to the instrument proper, and this cord is terminated in the transmitter housing of the handset. The two wires from this point to the receiver are moulded into the handle and are terminated at screwed bushes in the receiver housing. The receiver is of the inset type and is fixed to the microtelephone by means of two screws which not only serve for the mechanical fixing but also for the electrical connexion of the receiver to the circuit. The receiver cap screws directly on to the inset receiver and not to the handset casing. The transmitter inset is merely pressed into position along a centre guide pin which forms one of the connexions to the transmitter. The second connexion is made to the case of the transmitter inset by a double-contact flexible spring. The mouthpiece of the handset holds the transmitter in position and is fixed by a simple bayonet action which automatically locks to prevent unauthorized interference by the subscriber. When it is necessary to remove the mouthpiece for maintenance purposes a special key in the form of a small pin is inserted in a hole in the casing to release the locking device.

The handset illustrated makes no provision for cutting the transmitter out of circuit. Such a facility is not normally required except in very noisy situations. When a transmitter cut-out is wanted, a special form of microtelephone is provided which incorporates a press button switch in the handle.

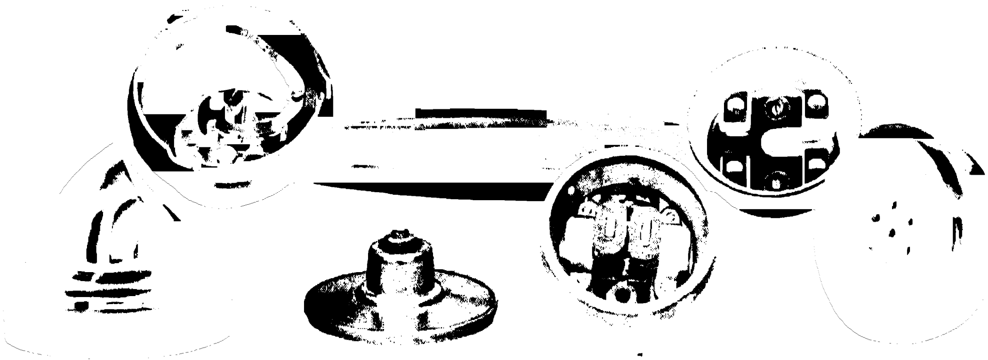


FIG. 219. THE COMPONENTS OF A MODERN HANDSET

Telephone No. 164.

Two-piece Moulded Telephone. Fig. 220 shows the standard telephone instrument for use when a separately mounted bell is required. The body of the telephone is a plastic moulding and is available in ivory, jade green, and Chinese red in addition to the standard black colour. The handset cradle is screwed to the main body of the instrument and

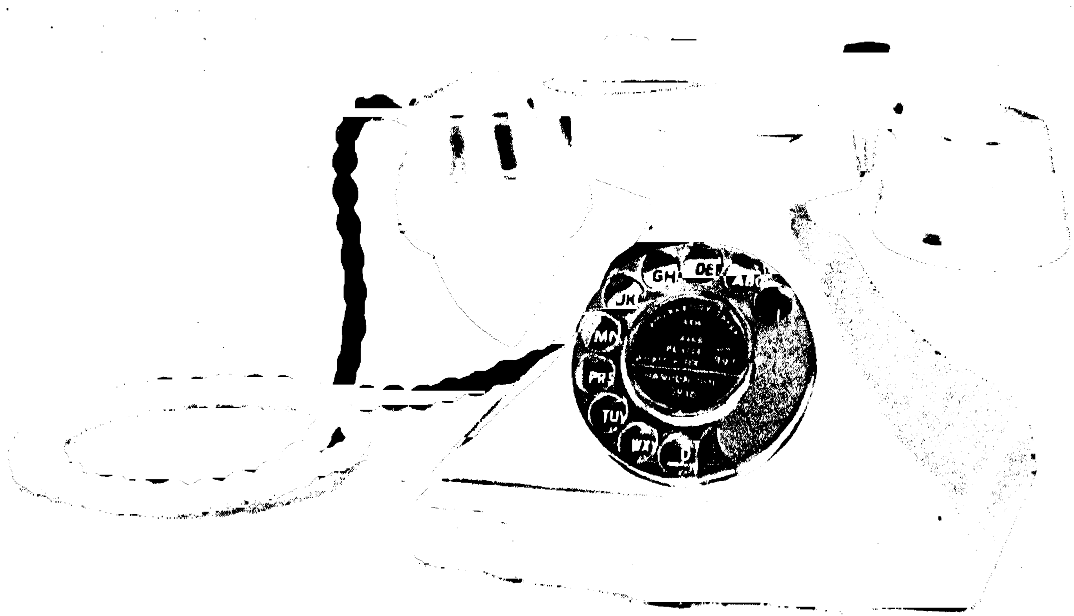


FIG. 220. MODERN TABLE INSTRUMENT FOR USE WITH SEPARATE BELL SET
Telephone No. 232.

the cradle switch is in the form of a moulded platform operating a vertical plunger. The body of the instrument accommodates the cradle switch springs, the induction coil, and, when required, the dial. The base of the instrument provides a tray to accommodate dialling codes and other information

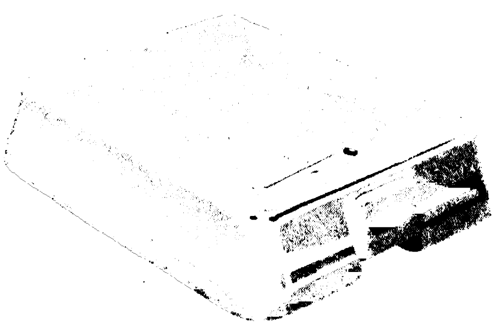


FIG. 221. MOULDED BELL SET FOR USE WITH TABLE INSTRUMENT
Bell Set No. 26.

required by the subscriber. The bell set used in conjunction with the hand microtelephone is illustrated in Fig. 221. The cover is a one-piece moulding and is so designed that the bell set can, if desired, be fixed below the telephone instrument in place of the normal base-plate with tray. The

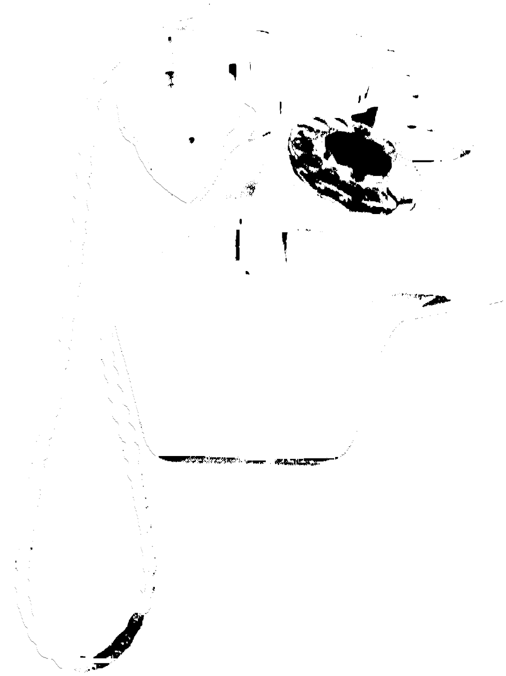


FIG. 222. TABLE TELEPHONE FITTED ON BRACKET FOR USE AS WALL INSTRUMENT

bell set merely contains the magneto bell and its associated 2 μF condenser, and can be located at any point convenient to the subscriber. No parallel instrument for wall mounting has been developed, but the two-piece hand microtelephone can be used as a wall telephone by the use of a mounting bracket as shown in Fig. 222.

A typical circuit of a two-piece microtelephone instrument for use in an automatic area is given in Fig. 223. The induction coil is of the A.S.T.I.C. type as described in Chapter V, whilst the dial off-normal springs are arranged to provide a spark quench circuit to the impulse contacts consisting of a 2 μF condenser and 30 Ω resistance in series. The 30 Ω resistance is also switched across the magneto bell to prevent bell tinkling during dialling. A three-way cord connects the instrument to a terminal strip, whilst a three-wire cable extends the connexions to the bell set. If the bell set is mounted near to the hand microtelephone, the three-wire cord can be run directly between the telephone instrument and the bell set without the use of a terminal strip and permanent wiring. It will be noted that terminals are provided in the bell set to cater for various forms of signalling. It is also possible to add an additional receiver to the

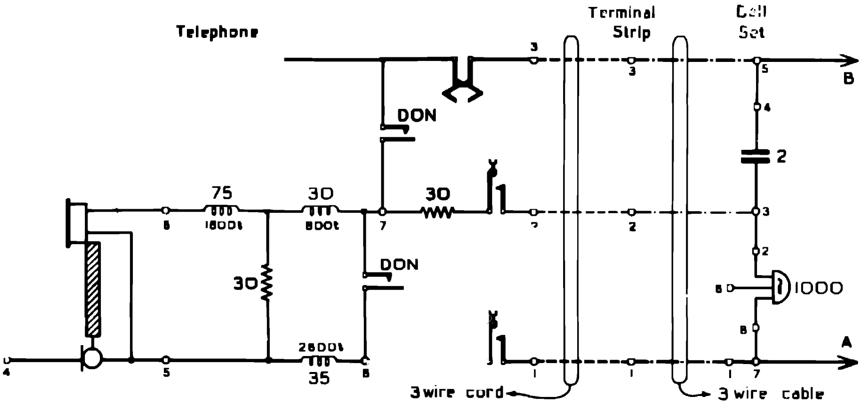


FIG. 223. CIRCUIT OF TABLE INSTRUMENT WITH SEPARATE BELL SET
Telephone No. 232 and Bell Set No. 26.

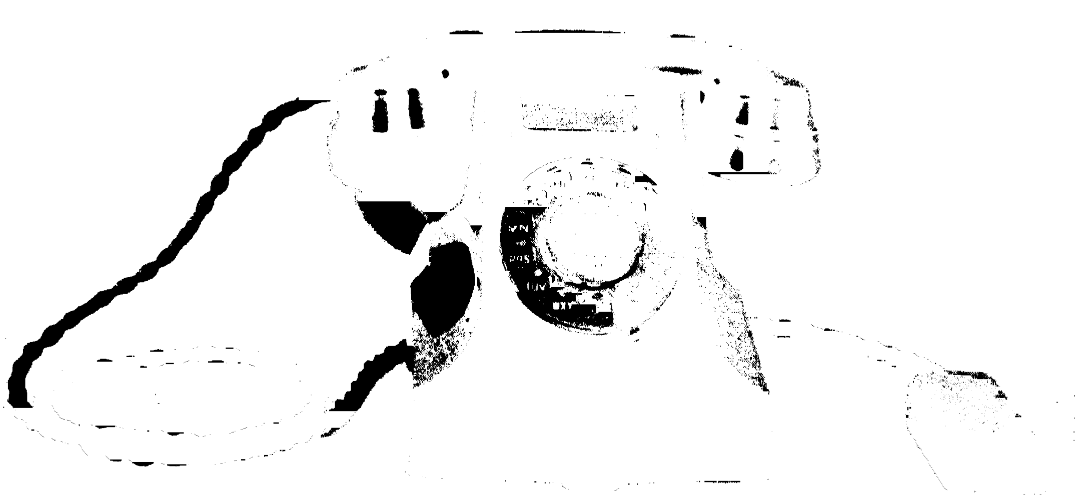


FIG. 224. ONE-PIECE COMBINED SET
Telephone No. 332LA.

telephone instrument by connecting to terminals 5 and 6.

One-piece Combined Set. The latest standard subscriber's instrument is illustrated in Fig. 224. All the apparatus (with the exception of the microphone and receiver) is accommodated in a one-piece moulded case of modern design. To differentiate from the H.M.T. instrument where the bell

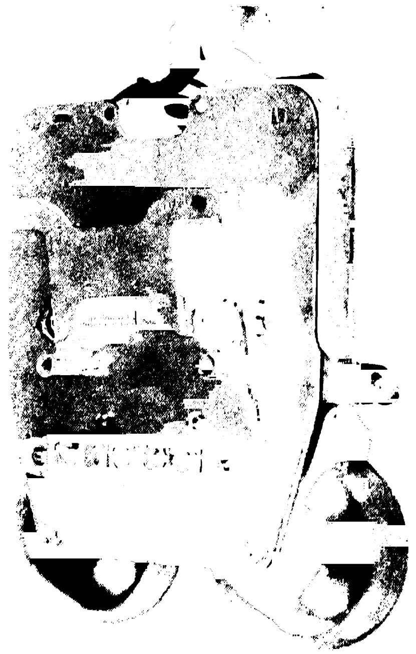


FIG. 225. CHASSIS OF COMBINED SET AS SEEN FROM ABOVE

set is a separate unit, the new instrument is usually referred to as a *one-piece combined set*. Each instrument has four main parts, viz.:

(*a*) The handset.
(*b*) The moulded case.
(*c*) The chassis.
(*d*) The base plate and directory tray.

The moulded case is a one-piece plastic moulding and is available in black, ivory, jade green, and Chinese red. The cradle for the H.M.T. is of an improved type to minimize breakage, and holes are provided when required for plunger type keys up to a maximum of three.

The mild-steel chassis (Figs. 225 and 226) is substantially the same for each type of telephone although the components vary with the circuit employed. All the wiring of the instrument with the exception of that to the dial is restricted to the chassis, which is fixed to the under-side of the case by three captive screws. This form of construction facilitates manufacture and produces a very

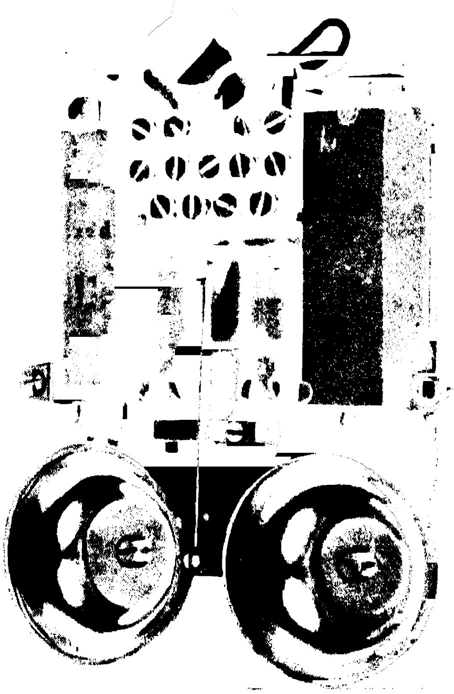


FIG. 226. CHASSIS OF COMBINED SET AS SEEN FROM BELOW

accessible lay-out for maintenance. The gravity switch is operated via plungers set in the cradle and has been carefully designed to minimize "sticking." The gravity switch springs are of the twin contact type to reduce failures.

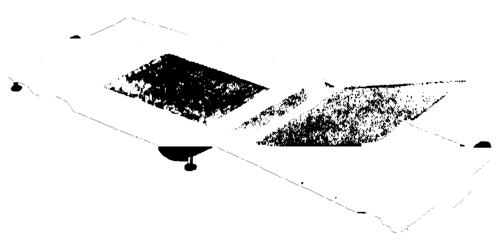


FIG. 227. BASE-PLATE OF COMBINED SET

The under-side of the instrument is closed by a base-plate (Fig. 227) which includes a tray where a card can be fitted to give dialling codes and other information to the subscriber. A wiring diagram

of the instrument is pasted to the base-plate so that it is visible when the tray is withdrawn.

Several types of key unit are available for use with the combined set. These key units are screwed to the upper face of the chassis and are operated by plungers passing through the case of the instrument. The key units provide from one to nine make-before-break spring combinations operated by one, two, or three plunger keys. An interesting feature of the key units is the latch bracket and control plate assembly which enables a standard key to be used for a variety of purposes (Figs. 228 and 229). By suitably adjusting the position of a slotted control plate, two of the three keys, *A* and *C* (Fig. 230) can be made either locking or non-locking, but the centre key *B* must always have a non-locking action. The latch bracket also provides facilities for the release of certain keys automatically when other keys are operated. There are eight alternative arrangements to cater for various types of installation. The slot cut in the upper rolled edge of the latch bracket normally prevents the operation of *B* from releasing *A* or *C*.

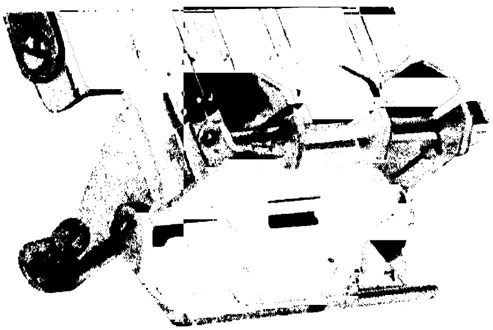


Fig. 228. Three-key Unit with Control Plate and Latch Bracket
Key No. 304A.

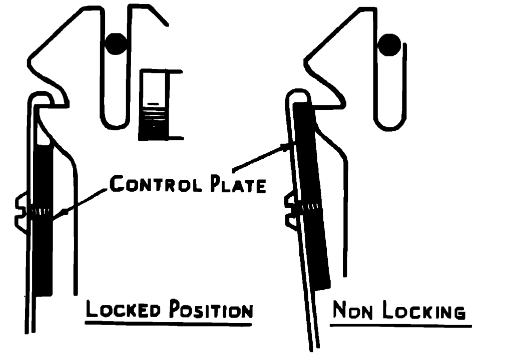


Fig. 229. Diagrammatic Cross-section of Locking and Non-locking Key Actions

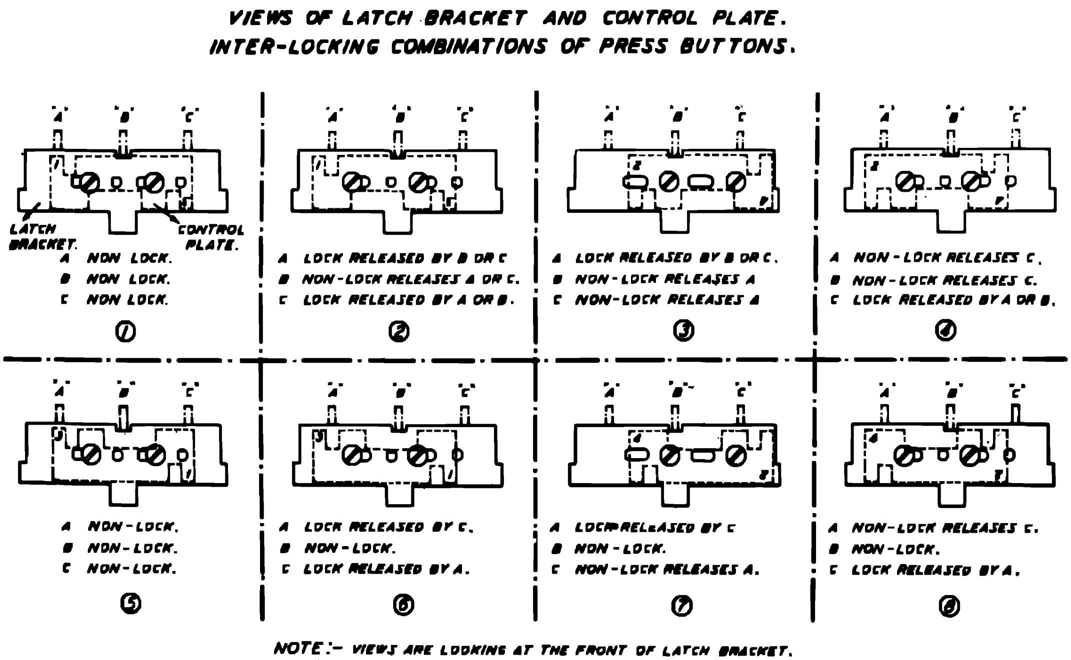


Fig. 230. Use of Control Plate to Give Various Combinations of Key Actions

but key *B* can be made to release other operated keys by adjustment of the control plate.

Fig. 231 shows a new type of wall instrument designed on the same lines as the one-piece table instrument. The general construction of the wall telephone is similar to that of the table instrument.

Circuits of Combined Sets. There are a number of separately coded standard instruments but, excluding the key circuits, the arrangements in all cases resolve to the four basic circuits given in Figs. 232 to 235. Fig. 232 is the standard circuit for C.B. and automatic areas. It includes the A.S.T.I.C. induction coil and the 0·1 μF condenser across the transmitter to by-pass radio-frequency currents. The dial off-normal springs are arranged to short-circuit the transmitter and receiver circuits as usual and shunt the bell to prevent tinkling. The dial spark quench circuit is formed by the 2μF condenser and the 30 Ω N.I. winding of the induction coil. The terminal arrangements provide full facilities for obtaining access to the bell circuit and to the transmitter and receiver for extension working. Fig. 233 shows a similar C.B. or automatic instrument with a trembler bell instead of the normal magneto ringer. The trembler bell circuit includes a choke and condenser to prevent the higher frequencies generated in the bell from passing to the external wiring where there is a danger of interference with speech conductors. This telephone is of course not used on direct exchange lines but as an extension telephone with d.c. signalling from the main instrument.

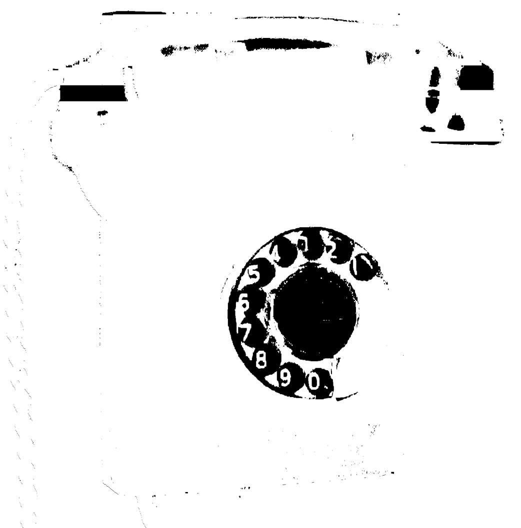


Fig. 231. Wall Instrument

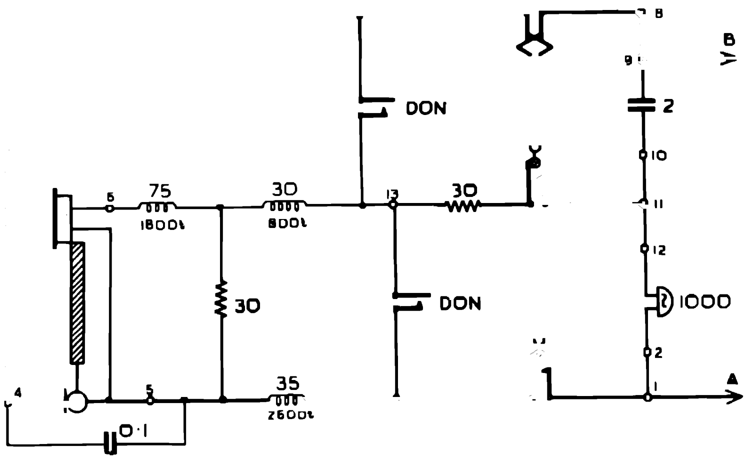


Fig. 232. Circuit of Combined Set for Use in Automatic Areas
Telephone No. 332.

Figs. 234 and 235 show the equivalent circuits for use on local battery systems or for long lines in C.B. and automatic areas. The dial is not provided except in the latter case. The dotted lines (Fig. 234) indicate the connexions of a magneto generator when required, and terminal 8 is provided for use in C.B.S. No. 1 areas where it is connected to terminal 7 and the bell is earthed at 2.

The Pendant Telephone. The pendant telephone illustrated in Figs. 236 and 237 has been introduced for use where it is desired to conserve desk or table space and where the subscriber desires the telephone to be fitted in an inconspicuous position. The apparatus consists of four units, i.e. the H.M.T., the switch-hook unit, the dial unit, and the bell set. Often the H.M.T. and dial units are fitted on the left- and right-hand sides respectively of the knee-hole of a desk, and hence the pendant telephone is sometimes known as a *knee-hole telephone*. The dial unit screws to the under-side of a convenient horizontal surface and is so arranged that the dial can be withdrawn when required for use. The switch-hook unit in conjunction with the standard handset makes a neat form

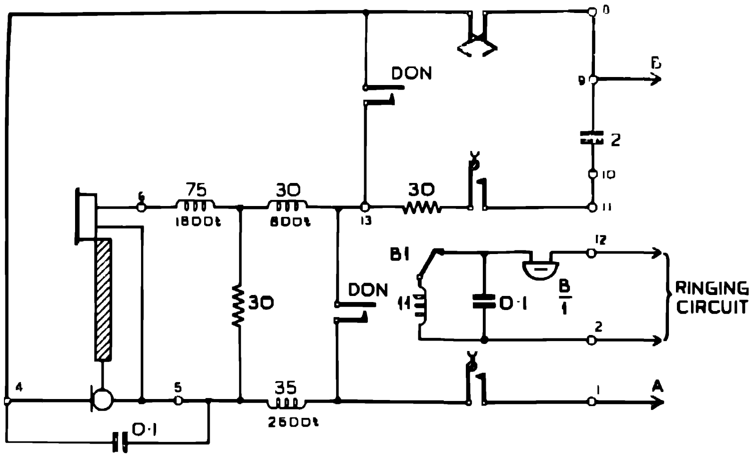


FIG. 233. EXTENSION INSTRUMENT CIRCUIT WITH TREMBLER BELL RINGING
Telephone No. 326.

of wall telephone when dialling facilities are not required. The circuit arrangements of the pendant telephone are similar to those of the standard instrument.

Flameproof Telephones. It is the policy of the Post Office in general to discourage the use of telephone apparatus in any situation where there is a risk of explosion. Nevertheless, flameproof apparatus has been designed and is installed in circumstances where the risk is not continuous and where the subscriber will accept full responsibility. Any piece of telephone apparatus is liable to produce sparks during its normal operation, for example at dial impulse contacts, switch-hook contacts, etc. If, therefore, special provision is not made, there is a grave danger of explosion if such sparks occur in the presence of inflammable gases. The British Standard Specification (B.S. 229) for flameproof apparatus lays down that the construction shall be such that the apparatus itself shall be strong enough to withstand an explosion within the instrument, and also that any flame or explosion shall not be communicated to the surrounding atmosphere. Fig. 238 shows the standard flame-proof telephone (Telephone No. 149) for use on an automatic system. The case is of heavy cast-iron construction and has an access door which is normally kept closed for protection from weather, dirt, etc. The circuit is similar to the standard A.S.T.I.C. telephone and the interior construction is so arranged that any component which may possibly produce a spark is enclosed in a separate air-tight box. The regulations prohibit the use of rubber glands, etc., for these air-tight compartments, and hence the compartments are fitted with lids machined to an accuracy of up to $\frac{1}{1000}$ in. The dial is fitted with a special slipping clutch. This provides that when the dial has been engaged and driven round to the finger stop, the finger-plate when released is disengaged from the dial mechanism and returns to its normal position very quickly under the control of a coil spring. It cannot be again moved from its normal position

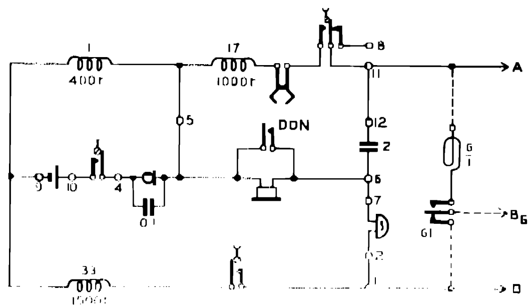


FIG. 234. CIRCUIT OF COMBINED SET FOR USE IN LOCAL BATTERY AREAS OR FOR LONG LINES IN C.B. AND AUTOMATIC AREAS
Telephone No. 396L.B.

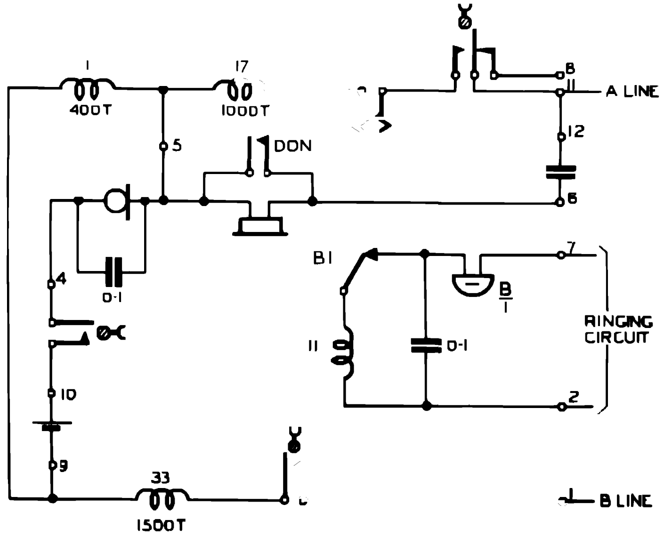


FIG. 235. EXTENSION INSTRUMENT CIRCUIT WITH TREMBLER BELL RINGING FOR USE IN LOCAL BATTERY AREAS
Telephone No 392L.B.

until the mechanism restores to normal. This device is introduced to prevent irregular operation of the



FIG. 236. PENDANT TELEPHONE
Telephone No. 246.

dial which might cause abnormal sparking and therefore a greater risk of fire. The Telephone No. 149 is not 100 per cent safe, since no provision is made for possible sparking due to breaks in the wiring of the instrument, in the cord to the H.M.T., etc. Very great care must therefore be taken in maintenance to ensure that attention is given to any loose parts, frayed or damaged cords, etc. When the flameproof enclosures have to be opened for maintenance purposes, exceptional care must be taken to ensure that loose material does not prevent a close fit of the machined surfaces.

In the flameproof telephone no attempt is made to prevent sparking, but the design is such that

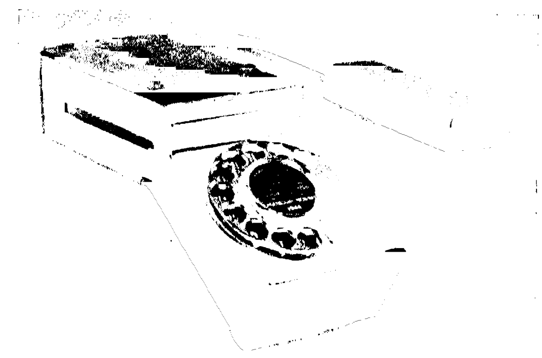


FIG. 237. DIAL UNIT FOR PENDANT TELEPHONE

there is little risk of such sparks igniting any inflammable gas. It is possible to design *intrinsically* safe telephones so that the energy of any sparks caused during the operation of the instrument

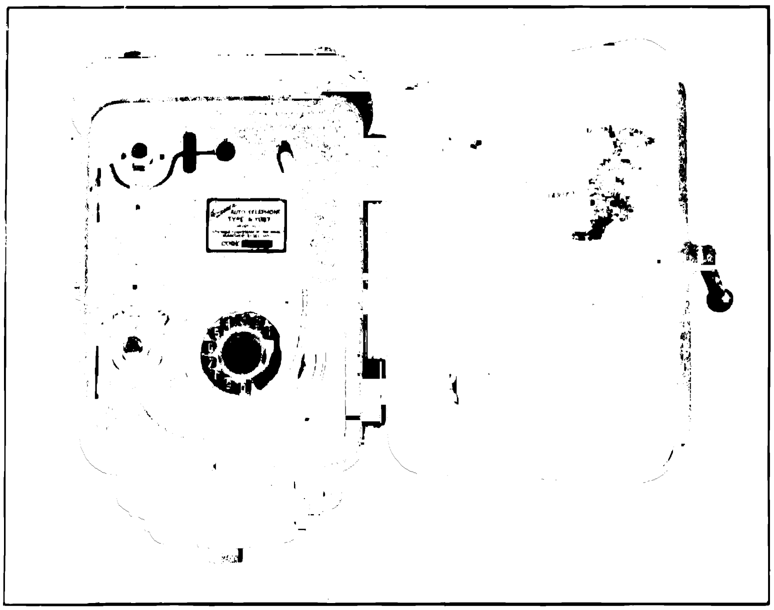


FIG. 238. FLAMEPROOF TELEPHONE
Telephone No. 149.

is below that required for the ignition of the most sensitive gases. It is not practicable to design an automatic or C.B. telephone on these lines since the line circuit itself is not intrinsically safe. A telephone has, however, been designed for use in

magneto areas (Telephone No. 153). It has the usual flameproof cover over the generator contacts, and shunts are provided across the generator, magneto bell, etc., etc., to limit the induced voltage in these components.

The lead-in for a telephone in a danger area should normally be run underground. The wiring either should be armoured cable or should be drawn into conduit which is not provided with inspection elbows or other points at which inflammable gases can enter. All the conduit should, of course, be effectively earthed.

Plan 1. A number of simple extension arrangements known as *Plan Numbers* are available to the subscriber. In the Plan 1 scheme up to six extensions can be placed in parallel on each exchange line. Incoming calls are received at one particular instrument designated the *Main Station* where a magneto bell is fitted. The extension instruments are fitted with trembler bells in lieu of the magneto bell. The main instrument is provided with a press button for each extension and can call the latter on a d.c. signalling basis. The standard combined sets provide for three press buttons as an integral part of the instrument but, when more than three extensions are required, separate bell pushes must be fitted. Any instrument can be used to originate calls, but there is no secrecy between the extensions and the main instrument. Plan 1 does not, moreover, provide for communication between the various stations of the installation, and due to the low line resistance required for signalling, the scheme is limited to internal extensions only.

The signalling circuits of a three-station Plan 1 installation for an automatic or C.B. area are shown in Fig. 239. The transmission and dialling circuits have been omitted for clarity, but the detailed circuit conditions can be readily seen by comparing with Figs. 232 and 233. The *A*- and *B*-lines are commoned to all instruments. A third conductor is provided to connect the receiver circuits of the extensions (terminal 11) to the condenser of the main instrument; the condensers of the extension instruments being disconnected. This wire prevents bell tinkling at the main instrument when a call is dialled from an extension. In addition to the three multipled wires, a separate conductor is required from the press buttons at the main instrument to the trembler bell at each extension. When the press button is operated, the trembler bell of the appropriate extension is energized from the battery received over the exchange line. In C.B.S and magneto areas a local battery is connected in the press button circuit.

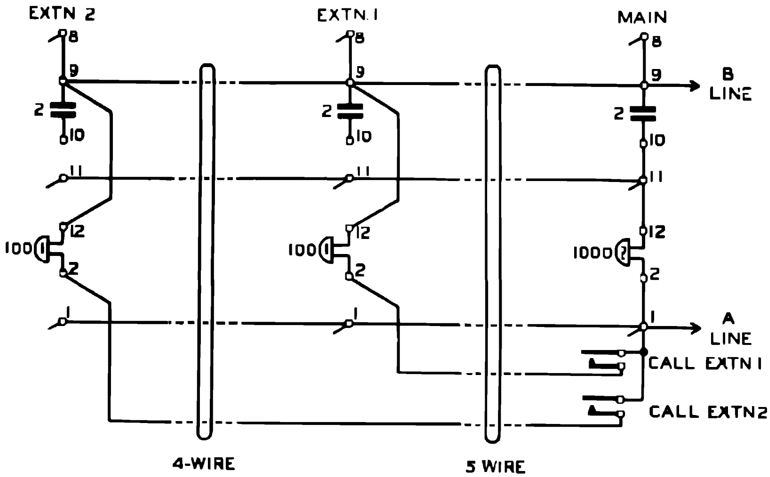


Fig. 239. Three-station Plan 1 Installation

Plan 1A. This plan number (Fig. 240) can be used up to a maximum of two extensions plus the main instrument in the same building. All instruments are provided with magneto bells which are arranged in series. Normally the extension bells are short-circuited by the locking type key on the extension instrument and all incoming calls are received at the main station. By depressing the key at any extension, incoming calls can be answered either at the extension or at the main instrument. As in Plan 1, outgoing calls can be set up from any station but there is no intercommunication or secrecy between stations. Sometimes a Plan 1A is superposed on a Plan 1 installation to provide night service facilities at a specified extension.

Plan 1B. Plan 1B is a very simple arrangement of telephones in parallel with no signalling facilities at the extensions (Fig. 241). It has a capacity for a total of six extensions all in the same building, and is largely used in big offices occupied by a number of staff and where the single bell can be heard by all the extensions.

Plan 3. Plan 3 provides for a main and one internal extension instrument with press button calling from the main to the extension. A locking press button is fitted at the extension instrument so that when a call has been established it is possible to cut out the main instrument and thereby obtain

secrecy on extension to exchange calls. A magneto bell is provided at the extension to receive any incoming calls should the press button be left in the secrecy position. As in the previous arrangements, Plan 3 is not designed to provide intercommunication between the main and extension. Fig. 242 shows the circuit arrangements. The exchange lines are taken to the main instrument via the extension, and key *S* is fitted to isolate the extension when required. The trembler bell at the extension must be mounted external to the instrument due to the presence of the magneto bell.

Plan 4. This plan has been designed specially to meet the needs of hotels, boarding houses, etc., where a single instrument may be required at any one of a number of points. The premises are wired with jacks located at all places where service may be required, and the telephone instrument is fitted with a plug. A magneto bell is fitted at the main position and a second bell is contained in the portable instrument. The circuit (Fig. 243) is arranged so that on incoming calls the bell rings at the main station and at the station where the instrument is plugged in. Care must be taken on this scheme to ensure that on an outgoing call the holding loop is not broken by removing the telephone from one position to another.

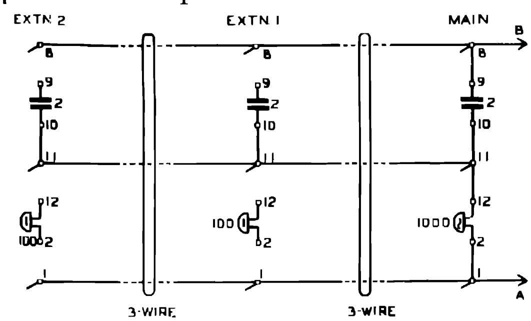


FIG. 241. PLAN 1B INSTALLATION

Intercommunication Switch. The extension arrangements so far described do not provide for communication between the main and extensions. To provide this facility a more or less complex switch is required. The P.O. Bell Set No. 20 illustrated in Fig. 244 provides for four switching conditions, viz.:

(1) *The main station connected to the exchange.* With the switch in this position the extension circuit is terminated on a magneto bell and a generator is provided to call the extension if required.

(2) *The main station connected to the extension.* The exchange line is connected to a magneto bell to receive an incoming call.

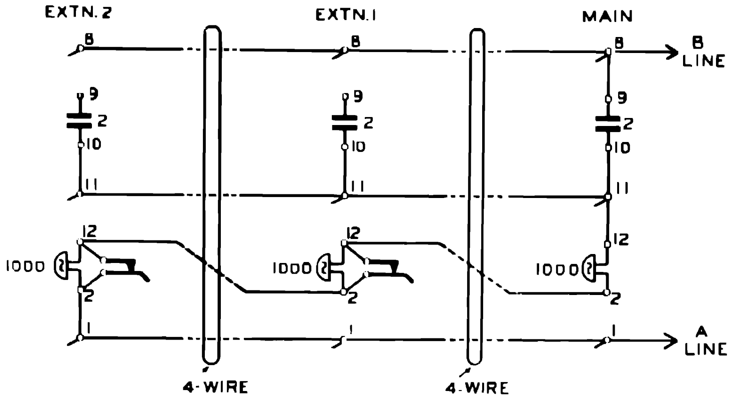


FIG. 240. THREE-STATION PLAN 1A INSTALLATION

(3) *The exchange connected to the extension.* The circuit provides for secrecy from the main instrument if required and a supervisory indicator in the bell set shows when an extension to exchange call is in progress.

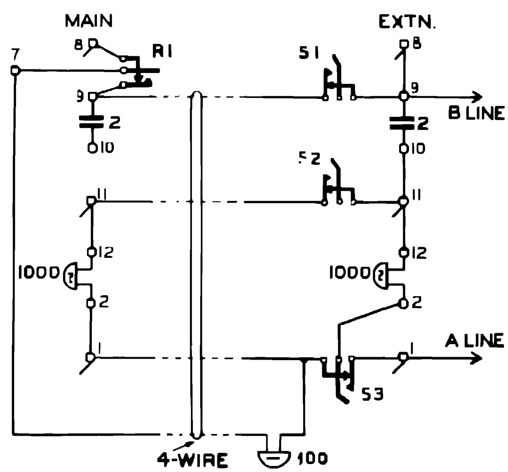


FIG. 242. PLAN 3 INSTALLATION

(4) *The main station connected to the extension and the exchange line held.* This condition is required so that an outgoing exchange call from the main station can be held whilst an inquiry is made to the extension.

The rotary switch contact springs are shown in

Fig. 245, whilst Fig. 246 gives the detailed connexions of the bell set. Simplified elements of the connexions of the Bell Set No. 20 in each of the four switching positions are given in Fig. 247.

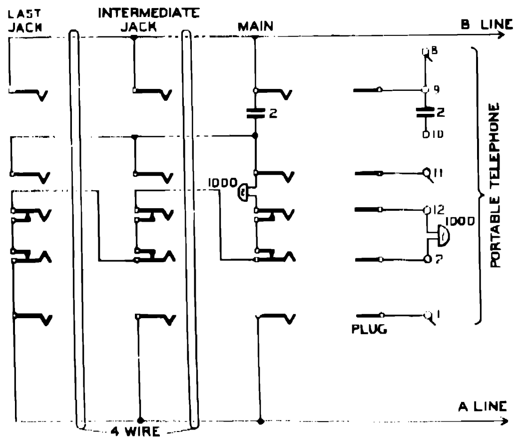


FIG. 243. PLAN 4 INSTALLATION

Circuit "1" is self-explanatory and the only point of interest in "2" is the introduction of a local 3 V battery to provide transmitter current on main to extension calls. The exchange is held with the

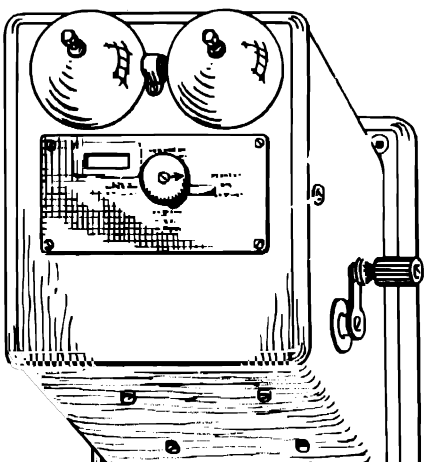


FIG. 244. INTERCOMMUNICATION SWITCH
Bell Set No. 20.

switch in position (3) by one 500 Ω winding of the magneto bell. The use of the bell as a hold coil enables the subscriber to be rung if he should accidentally leave the switch in the "Exchange Hold" position. The supervisory relay *S* (switch position (4)) is connected in series with one line and operates from the normal line current to the extension. During conversation, **S1** disconnects the magneto bell in the bell set and places a 1 μF condenser in parallel with the existing 2 μF condenser across the *S* relay, thereby providing a very low impedance path for the speech currents. *S* also acts as a supervisory indicator by showing a white disc when operated. When the extension hangs up at the end of the conversation, *S* releases and

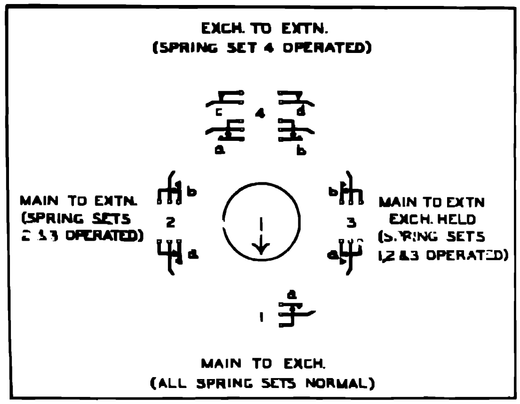


FIG. 245. FOUR-POSITION KEY OF BELL SET NO. 20 AS SEEN FROM REAR

at *S1* places a magneto bell in series with a 1 μF condenser across the exchange line. This provides for any incoming call received before the switch is restored.

Plans 5 and 7. The P.O. Plan 7 is the straightforward arrangement using Bell Set No. 20 with a single extension instrument. The detailed circuit arrangements can be readily visualized from an examination of Figs. 246 and 247. Normally generator signalling is employed between the main and extension and a generator is fitted to the extension instrument. This allows for external extensions where the line resistance is too high for the trembler bell circuits of the earlier plan numbers. If the extension is in the same building as the main, push button signalling from the extension to the main may be employed if desired, thereby avoiding a generator at the extension instrument. Plan 7a is a variation of Plan 7 in which the straps of the bell set are arranged to give secrecy on extension to exchange calls.

Plan 5 and Plan 5a (secret) have been developed to avoid the provision of a private branch switchboard when a second extension is required. The two extensions are placed in parallel and two non-locking press buttons on the main instrument allow

either to be rung at will. To call an extension it is necessary to hold down the appropriate press button whilst the bell set generator is turned. As in Plan 7, generator or press button calling may be employed between the extensions and the main instrument. Fig. 248 shows the circuit arrangements when press button calling is employed. Night service facilities can readily be given on a Plan 7 installation by placing the bell set switch in the exchange to extension position. On Plan 5 an additional locking key must be provided to short-circuit the call button of the selected extension at the main instrument.

Table Pattern Intercommunication Switch. Fig. 249 illustrates a new type of switch unit for use on Plans 5 and 7. The switch unit (Bell Set No. 39) is designed to fix to the base of the standard two-piece instrument and the complete assembly forms a very compact installation for table use. The facilities provided are substantially similar to those of the Bell Set No. 20 already considered but certain new circuit features have been introduced. One of the great disabilities of a Plan 7 with a Bell Set No. 20 is that there is a danger of the subscriber irregularly holding exchange equipment by leaving the switch in the "exchange hold" position. With the Bell Set No. 39 it is impossible to leave a holding condition on the exchange after the termination of a call. This is achieved by the introduction of additional cradle switch contacts on the telephone of the main instrument which are connected in the 100 Ω hold circuit. The holding condition is therefore removed as soon as the main instrument receiver is replaced. A second feature of the new bell set is the prevention of the main instrument from dialling when the switch is in the extension to exchange position. With the non-secret arrangement on a Bell Set No. 20 installation, operation of the dial at the main instrument interrupts conversation on extension-to-exchange calls.

The circuit arrangements of the Bell Set No. 39 are designed for press button signalling with buzzer calling signals from the extension to the main and from the main to the extension. Since d.c. signalling cannot be provided between an external extension and the main instrument, it is necessary on external extensions to provide a separate hand generator for calling the main instrument. The switch is of very robust design and has four positions. Counting from the left these are:

1. Extension to exchange.
2. Speak to extension—exchange held.
3. Speak to exchange.
4. Speak to extension.

By this arrangement it is possible to extend an exchange call to an extension without breaking down the connexion. Thus an incoming call is received at the main station with the switch in position 3. The switch is moved to position 2 whilst the extension is being called and the exchange line is held whilst inquiry is being made. Finally, the switch is moved to position 1 when the extension is in direct communication with the exchange.

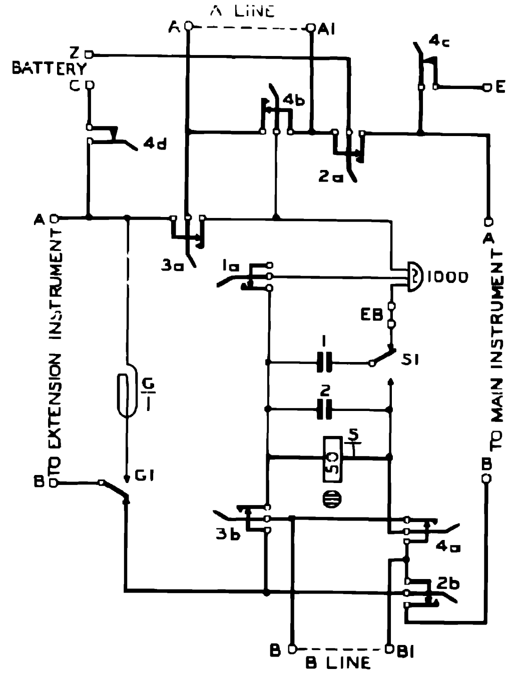


Fig. 246. Internal Connexions of Bell Set No. 20

The rotary switch, the supervisory relay, and the various miscellaneous components are shown more clearly in Fig. 250. A machined block of metal forms the main body of the switch mechanism and is fixed to the base-plate by four screws. Inside the blocks are housed a solid brass cam and four ¼ in. steel ball bearings. The latter are forced against the cam by the spring steel buffers of the spring sets which are operated when the buffer springs are allowed to force the ball bearings into dome-shaped cavities in the cam. The supervisory indicator is a standard 3000-type relay with one change-over spring set and an indicator flag attachment. The flag signal is visible through a window in the bell set cover to the right of the switch lever. The bell set also includes the calling buzzer, which is fitted with a suppressor unit to quench sparking at the buzzer interrupter contacts and to reduce electrical interference with telephone

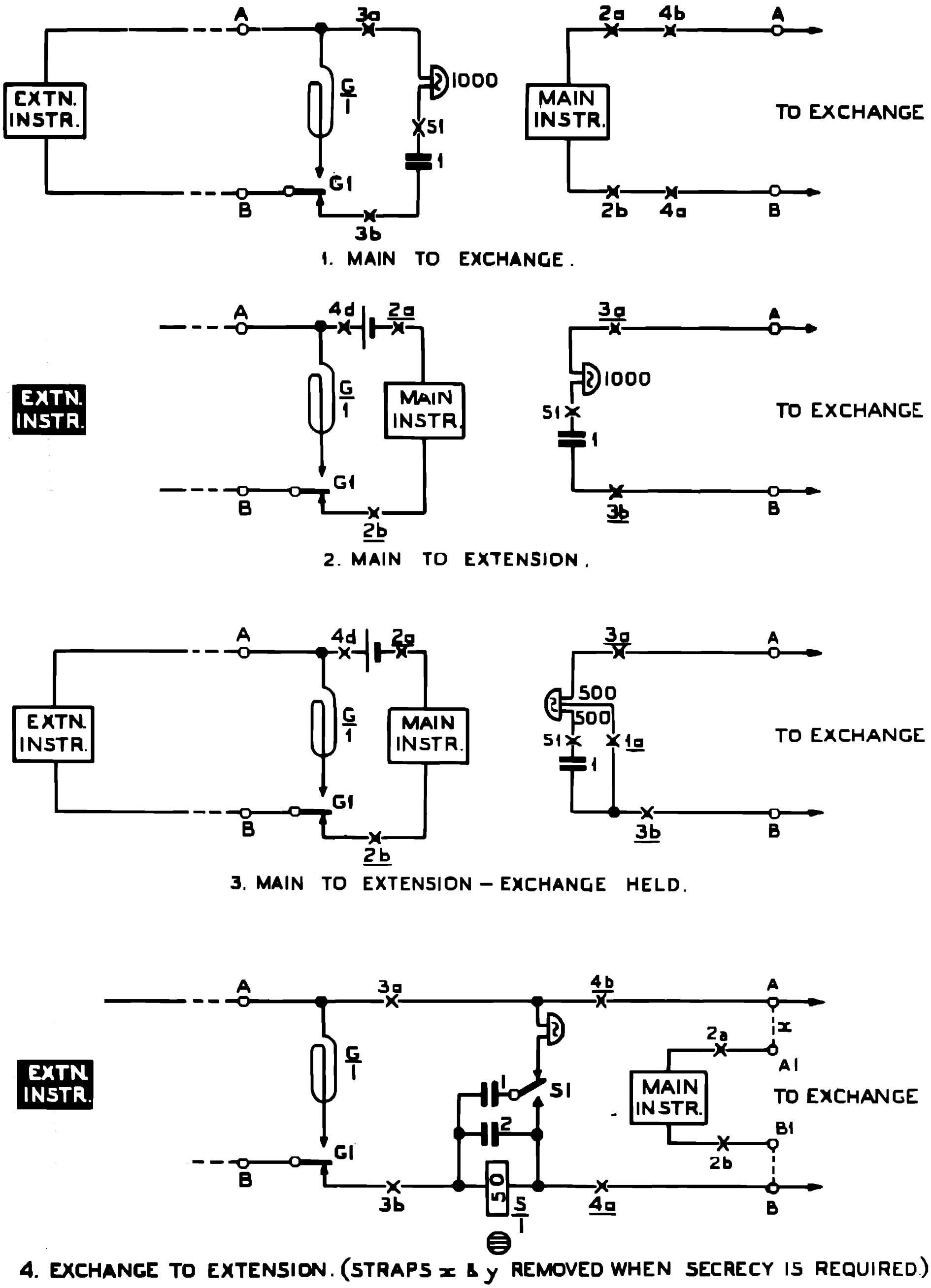


Fig. 247. Simplified Connexions of Bell Set No. 20

Spring sets in normal position shown, e.g. 3a.
Spring sets in operated position shown, e.g. <u>4a</u>.

circuits and radio receivers. It will be noted that two press buttons are provided for use with a Plan 5 installation. On Plan 7 installations only one press button is required, the remaining button being replaced by a suitable dummy cover plate. Fig. 251 shows the connexions of the Bell Set No. 39 and its associated telephone on a Plan 7 installation. For Plan 5 working, a second instrument is connected in parallel with the first extension and terminal No. 9 of the bell set is the signalling wire from press button No. 2. As with the Bell Set No. 20, the installation can be provided with or without secrecy on extension to exchange calls. If secrecy is not required, terminals 1—2 and 3—4 are strapped. It will be noted that a separate bell set is provided for the receipt of incoming exchange calls.

Other Plan Numbers. In addition to the more popular plan numbers already considered, there are a number of less common arrangements. In Plan 8 (Fig. 252) a single extension can be connected with either of two exchange lines by the operation of a switch or locking press key at the extension instrument. It is designed to avoid the provision of a small switchboard where three

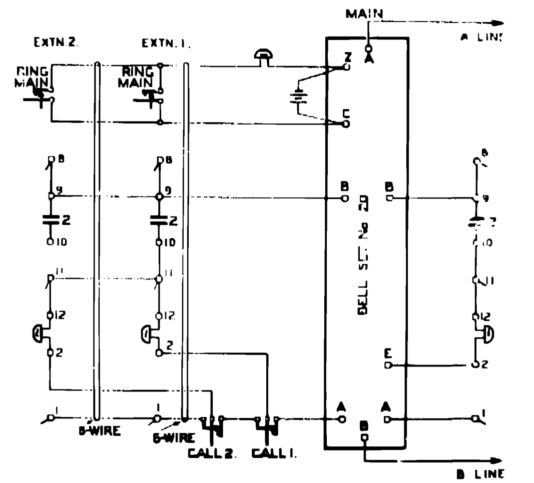


Fig. 248. Plan 5 Installation with Trembler-bell Signalling

stations and two exchange lines are required. Trembler bell signalling is provided from the main stations to the extension, but there is no secrecy

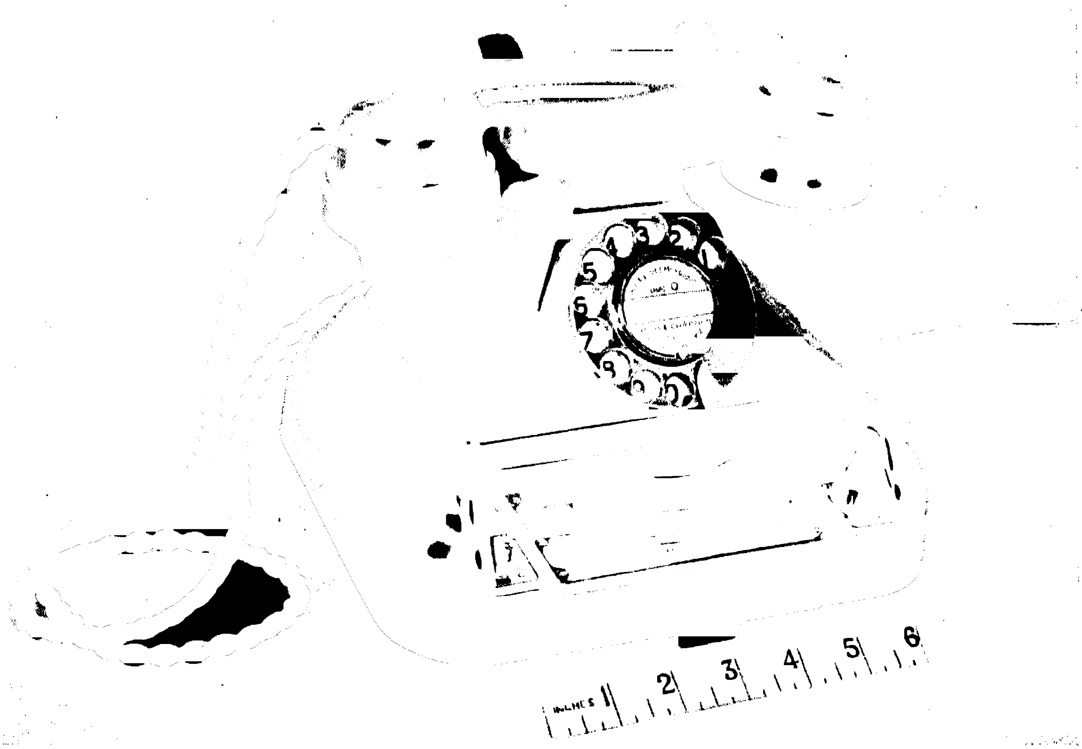


Fig. 249. Table Pattern Intercommunication Switch
Bell Set No. 39.

or intercommunication between instruments. Plan 8A (Fig. 253) which is available on C.B. and automatic systems, is similar to Plan 8 but secrecy is provided for the extension on exchange calls. A special box contains a two-position switching key together with a supervisory indicator per exchange line. The indicators are, of course, necessary to show when the exchange lines are being used by the main instruments.

Plan 9 (Fig. 254) provides for two lines from a private manual branch switchboard to an extension. The arrangement is intended to meet cases where a subscriber would otherwise require a house telephone for the purpose of consultation with other departments. The switching key is so arranged that incoming calls are received on No. 1 extension line. By operating the key, an outgoing call can be made on the second line and at the same time a bell and holding circuit is provided on the first line.

Plan 10 (Fig. 255) is also designed for an extension on a private branch switchboard. It provides a means of making an established call strictly private by intercepting the exchange lines between the switchboard and the exchange. In earlier installations the extension instrument was terminated on a plug, and break jacks were provided in the exchange line circuits. With the modern combined set, plunger keys on the instrument are used to intercept. An outgoing exchange call is set up via the switchboard in the usual way and when the call is established the private branch exchange operator advises the extension of the number of the exchange line used. By depressing the appropriate key at the extension, the line is cut away from the switchboard and full secrecy is

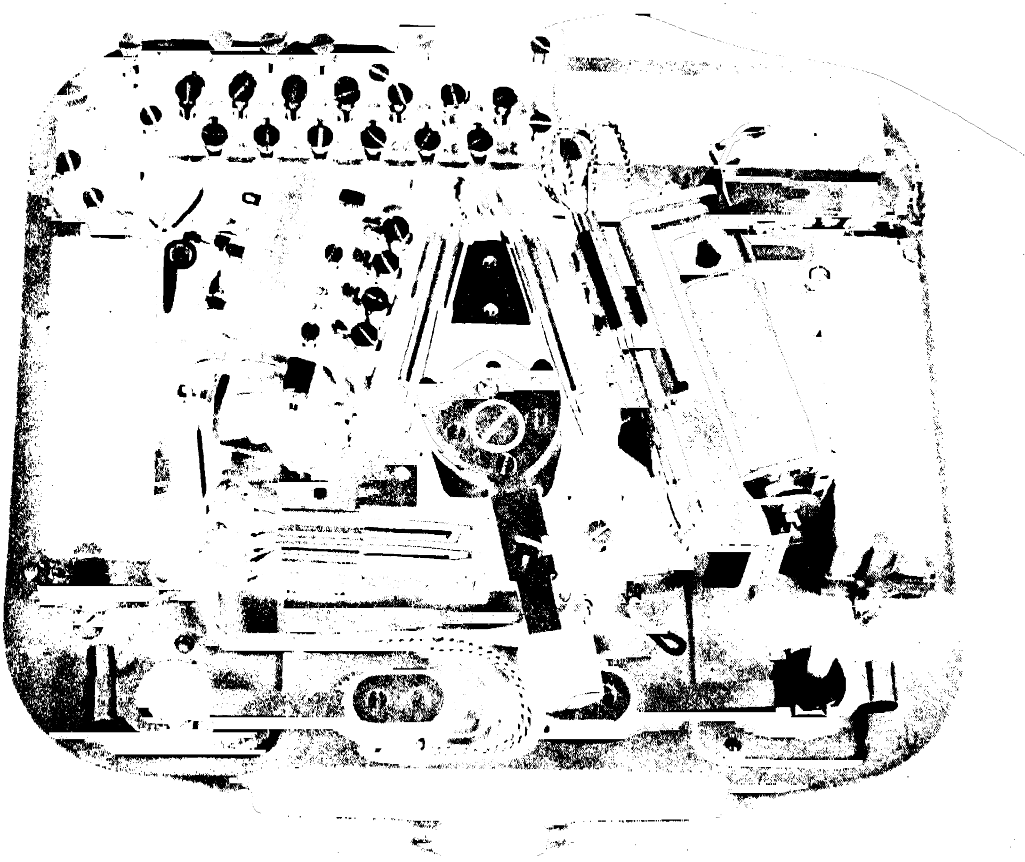
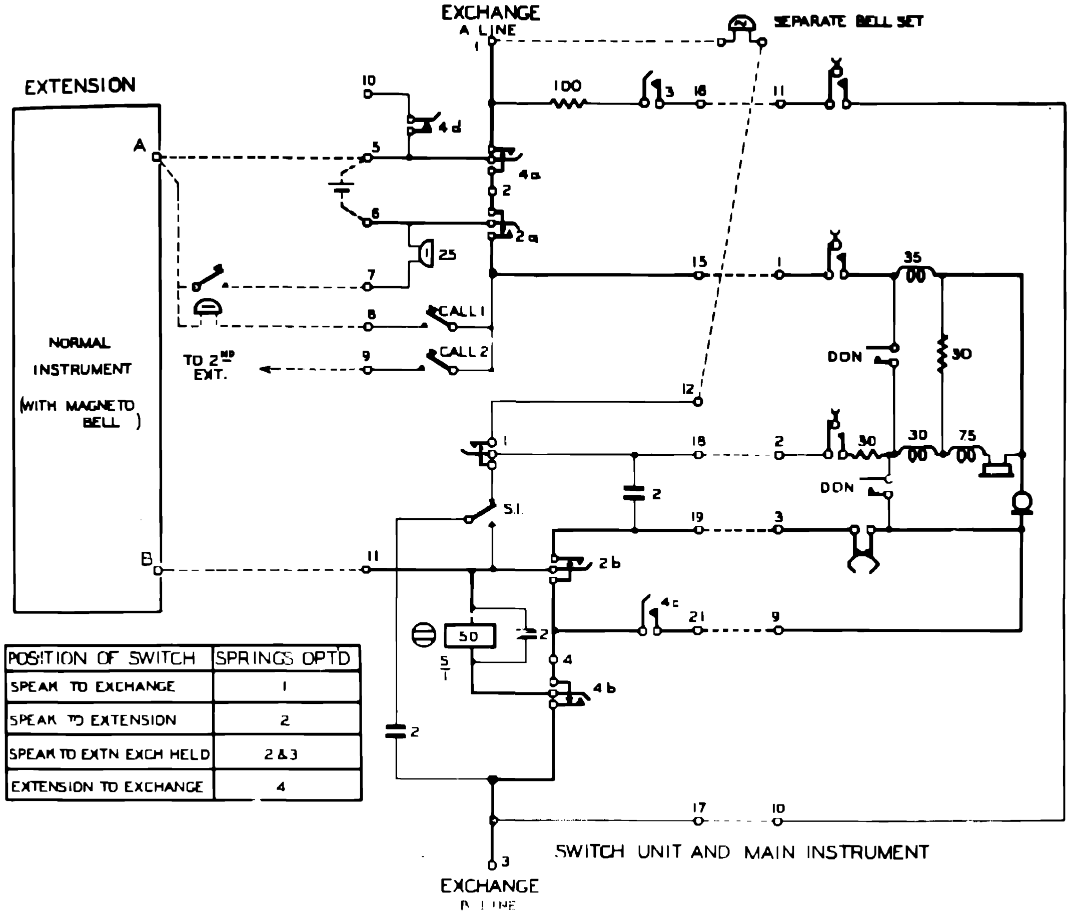


Fig. 250. Chassis of Bell Set No. 39.



POSITION OF SWITCH	SPRINGS OPTD
SPEAK TO EXCHANGE	1
SPEAK TO EXTENSION	2
SPEAK TO EXTN EXCH HELD	2 & 3
EXTENSION TO EXCHANGE	4

Fig. 251. Plan 7 with Internal Extension and Bell Set No. 39

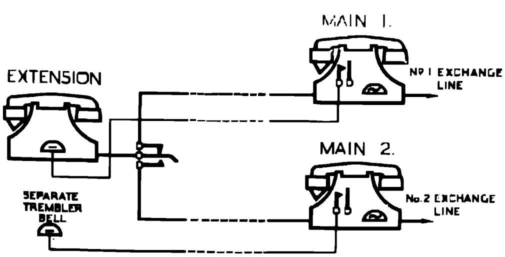


Fig. 252. Plan 8—Two Exchange Lines with One Extension

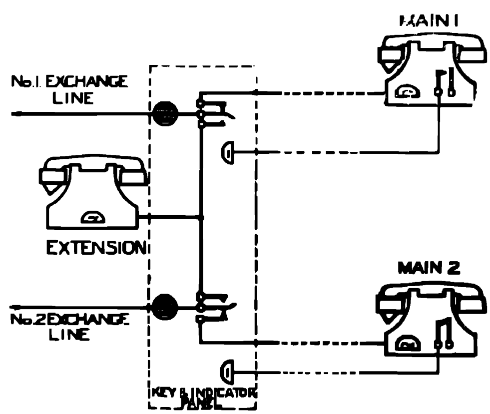


Fig. 253. Plan 8A—Two Exchange Lines with Secrecy at Single Extension

obtained. The circuit is arranged so that when either exchange line key is operated a magneto bell is placed across the exchange line circuit to receive an incoming call from the switchboard. It is apparent that there can be only one Plan 10 arrangement on any single installation.

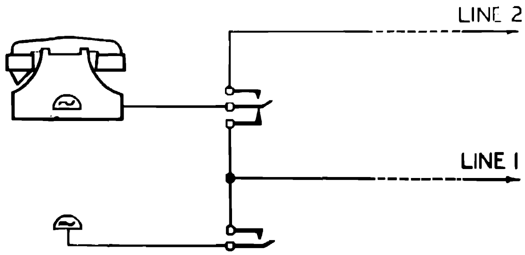


FIG. 254. PLAN 9—ONE TELEPHONE WITH TWO LINES

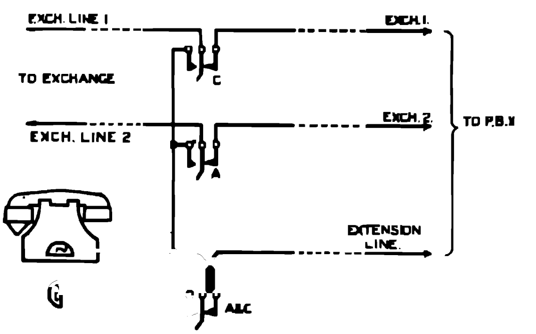


FIG. 255. PLAN 10—EXTENSION OF PRIVATE BRANCH EXCHANGE WITH SECRECY ON EXCHANGE LINE CALLS

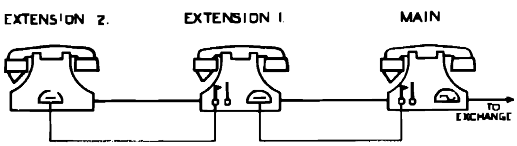


FIG. 256. PLAN 11—SIMPLE EXTENSIONS WITH FILTER FACILITIES

Plan 11 (Fig. 256) is a variation of Plan 1 to meet cases where it is desired to "filter" incoming calls through one extension before passing them on to a second extension. It is mainly used to prevent a principal from being troubled unnecessarily.

Instrument Cords. Flexible connexions are extensively employed in telephony, but every effort is made to avoid them wherever possible as they constitute possibly the weakest link in the chain of conductors which form the speaking circuit. There are numerous types of flexible cord to meet particular conditions. The most common usage is possibly in connexion with subscribers' instruments, although they are used also to a considerable extent at telephone exchanges of the manual type. In order to obtain the requisite flexibility, the conductor usually consists of an extremely thin copper tape (about $\frac{1}{1000}$ in. thick) spiralled upon a silk thread. This type of conductor is often known as a *tinsel* conductor, and although it is highly satisfactory with the small currents and normal high impedances of telephony, the current carrying capacity and the ohmic resistance must be considered when the conductor is required to carry heavy signalling currents. The resistance of a tinsel conductor is in the order of $0{\cdot}25\,\Omega$/yd. In instrument cords the tinsel is covered by a silk braiding followed by a second outer braiding of mercerized cotton. (Fig. 257.) The insulated conductors are usually plaited to form three-way, etc., cords to meet the circuit requirements. It is found that the plaited type of cord used on telephone instruments is less prone to kinking than cords of the round or solid type. Where the cord is required to withstand frequent and sharp bending the insulated tinsel conductors are interwound with cotton lappings to form a cord of circular section. Where a waterproof cord is required (e.g. for call offices and instruments in damp situations) the insulated conductors are lapped with an india-rubber tape so applied that the edges of consecutive turns overlap. The individual conductors so treated are served with a further lapping of soft cotton and the cord is finally braided with mercerized cotton.

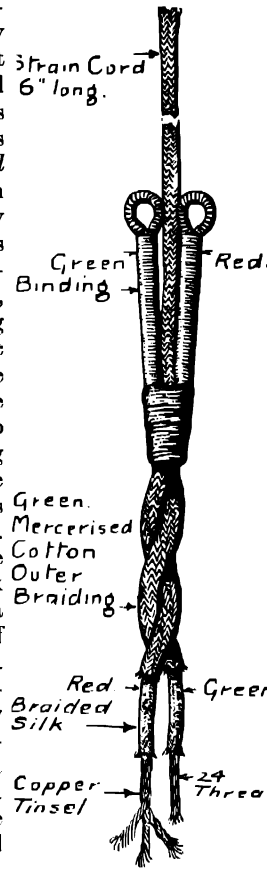


FIG. 257. TYPICAL TWO-WAY INSTRUMENT CORD

A number of experiments have been made in recent years in an endeavour to develop a reliable extending cord for telephone instruments. Experimental samples have been manufactured which can be stretched to double their normal length and

which give satisfactory performance under life tests.

The Autodial. The Autodial is a mechanism designed to facilitate the setting up of calls to numbers which are frequently required. It is of great advantage to a busy subscriber who requires to make repeated calls to a small circle of business associates. The Autodial can be fitted to any telephone instrument which is normally provided with a dial. It consists of a box unit (Fig. 258) on top of which appears a list of the names and telephone numbers of the subscribers with whom the renter of the device chiefly communicates. When one of these subscribers is required it is necessary only to lift the instrument handset, to select the name of the subscriber, and to depress a lever on the front of the Autodial. The Autodial then automatically sends out the required series of impulse trains. The time taken for the Autodial to pulse out is, of course, the same as the normal dialling time, but its use enables the subscriber to concentrate on other work during the process of setting up a call.

Two patterns of Autodial, Autodial No. 1 and Autodial No. 2, are available with capacities for 25 and 50 numbers respectively. One number is reserved for test purposes, leaving 24 and 49 numbers respectively for the subscriber's use.

The mechanism of the Autodial is illustrated in Figs. 259 and 260 whilst the electrical connexions are shown in Fig. 261. The mechanism consists essentially of a number of castellated discs (25 or 50) fixed to a common spindle. Each disc, which has 120 castellations initially, is prepared by cutting off selected teeth to give any desired combination of impulses. The prepared disc presents the appearance of a toothed wheel having a series of sets of teeth, each set of teeth being separated by a space corresponding to the inter-digit pause, and the number of teeth in each set is equal to the number of impulses required for that digit. For example, if the number 2460 is required, the disc would have the first two teeth (for the digit 2) then a space where eight teeth are removed to provide an interdigit pause of about 800 msec, followed by four teeth corresponding to the digit 4, then another space and so on.

The motive power is provided by a coiled spring

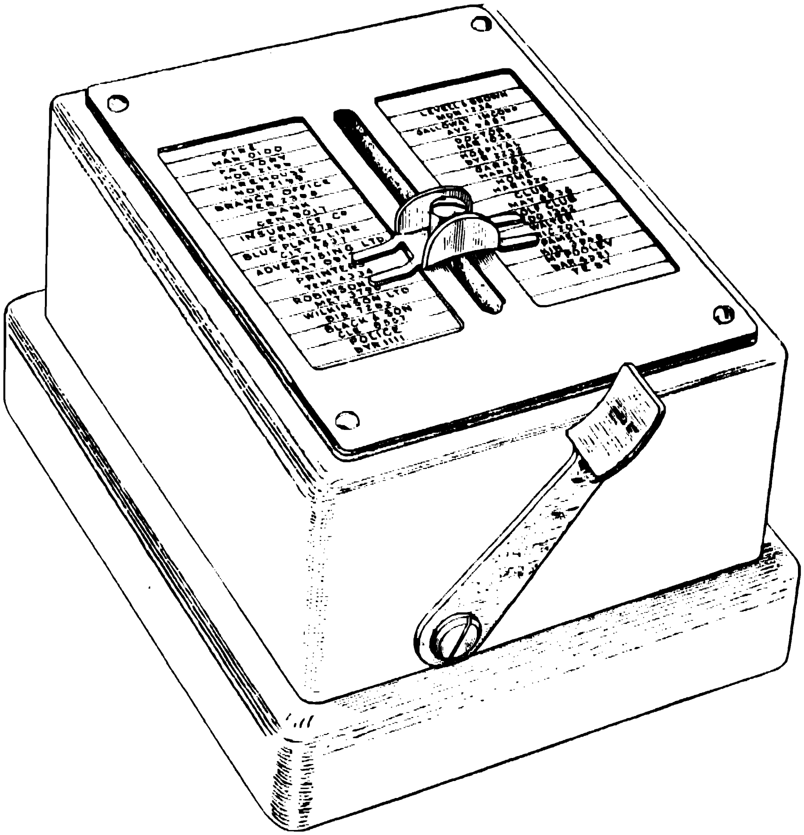


FIG. 258. AUTODIAL
Autodial No. 1.

which is wound on the depression of the start lever and, on the release of the latter, rotates the discs at a uniform speed which is controlled by a governor. The drum makes one complete revolution in approximately 12 sec. The number selecting device is in the form of a sliding carriage termed the *selector carriage* which may be moved longitudinally over the drum. The selector carriage on its upper side carries a pointer which indicates the name and number selected. On the under-side of the selector carriage, a pair of impulse-masking springs are attached. These masking springs are connected in parallel with the impulse springs of the mechanism.

Normally the impulse-masking springs are open, but when the associated pawl falls into the slot for each interdigit pause, the masking springs short-circuit the impulse springs to prevent the transmission of impulses to line. The impulsing mechanism is in the form of a butterfly of insulating material which revolves between two contact springs. These springs impulse continuously during the rotation of the discs. Off-normal springs which

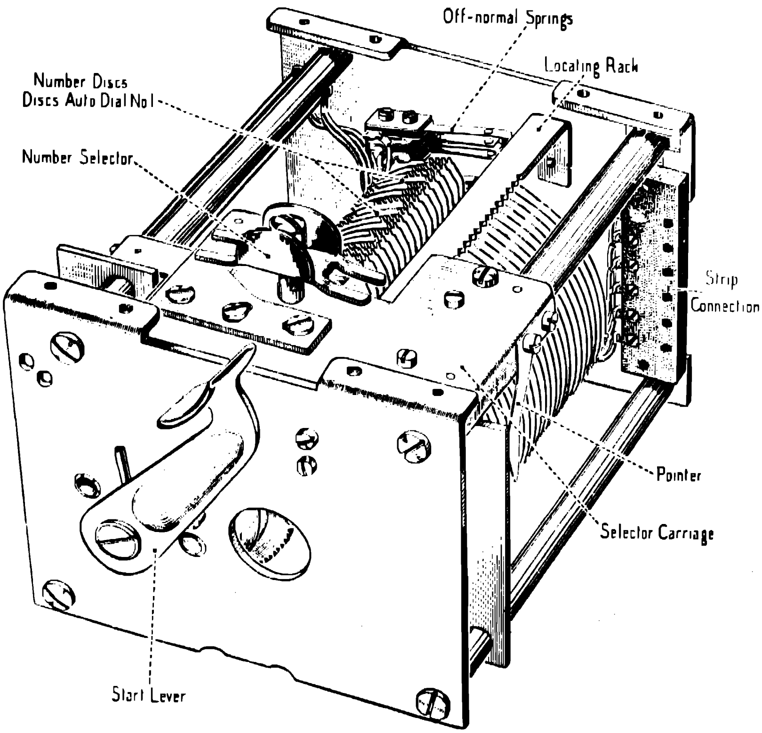


FIG. 259. MECHANISM SEEN FROM FRONT

serve the same function as those on the standard dial operate immediately the Autodial moves off normal and remain operated until the mechanism again comes to rest after all digits have been transmitted.

The Autodial is connected to the instrument circuit with its impulse springs in series with those of the normal dial and with the off-normal contacts in parallel with the dial off-normal springs.

Call Offices. The term *call office* refers to any installation provided primarily for the casual telephone user. If an attendant is available, arrangements can be made for him to collect the appropriate fee and if necessary to set up the required call. By far the majority of call offices are unattended and are equipped with *coin-collecting boxes* (C.C.B.) which are designed to receive the appropriate coins and ensure that the correct fee is inserted. Coin-collecting boxes may be of two types; *postpayment* boxes in which the fee is demanded and checked by the operator after the desired connexion has been set up, and *prepayment* boxes in which the fee must be desposited before the exchange can be called. With postpayment coin-collecting boxes, the operator must give special attention to the line until the called party has replied and until the coins have been inserted and counted. Moreover, the postpayment principle is difficult to adapt to an automatic area. Prepayment coin-collecting boxes are therefore fitted in all C.B. and automatic areas. Postpayment boxes are restricted to local battery manual systems (C.B.S. Nos. 1, 2, and 3 or magneto) and where call office facilities are required on an extension from a private branch exchange.

Prepayment C.C.B.s. The standard Post Office prepayment coin-box consists of a pressed steel case, parkerized and stove enamelled as a protection against corrosion, and divided into two compartments. The top portion houses the mechanism (Fig. 262) and the lower portion forms a cash box, independent access being provided by two separate locks. On the top of the box three slots are provided and marked "Penny," "Sixpence," and "Shilling," respectively. The size of each slot is such as to prevent the use of coins of a larger size than that marked opposite the slot. If smaller coins are inserted they are rejected by the coin gauges and returned to the caller. The coins after insertion are held in suspension in a pivoted container which is controlled mechanically by two press buttons A and B. On a successful call, the depression of button A deposits the coins in the cash-box beyond the further control of the caller, and auxiliary contact springs set up the necessary circuit conditions for speech. If the call cannot for any reason be completed, the depression of button B returns to the caller any coins held in the container.

The insertion of coins in excess of the local fee as required on junction and trunk calls, etc., is checked by the controlling operator by means of gong signals. Each penny inserted strikes a wire gong once, each sixpence inserted strikes a bell gong

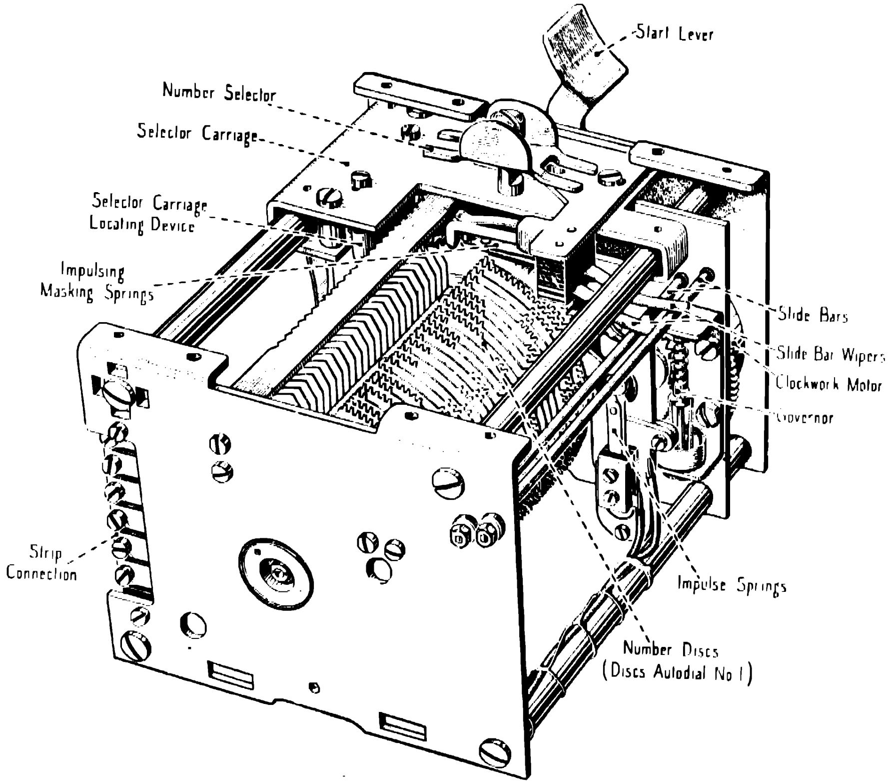


FIG. 260. MECHANISM SEEN FROM REAR

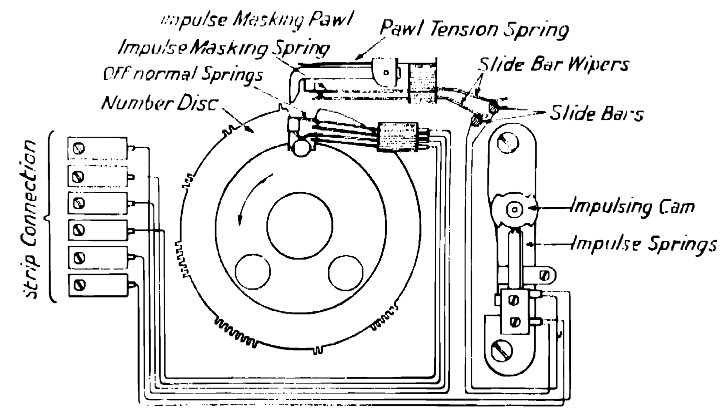


FIG. 261. INTERNAL CONNEXIONS OF AUTODIAL

once, whilst each shilling strikes the same bell gong twice. The gong signals are made audible to the operator by means of a small microphone fitted inside the bell gong. The whole mechanism of the coin-box is hinged to facilitate maintenance and the electrical connexions are made by means of a special plug and jack. The same coin-box is used in both manual and automatic areas but in the former case an auxiliary relay unit is required.

Single Button and Buttonless C.C.B.s. The Post Office has standardized the two-button type of prepayment coin-box. C.C.B.s have, however, been designed and have been used to some extent abroad where the A and B button functions are carried out automatically. In the one-button type, the A button is eliminated by the provision, in series with the line, of a polarized relay, which responds to a reversal of line current when the called party answers. The operation of this relay releases the pivoted coin container which moves to deposit the coins in the cash-box. The B button is retained to swing the coin container to the refund chute for ineffective calls.

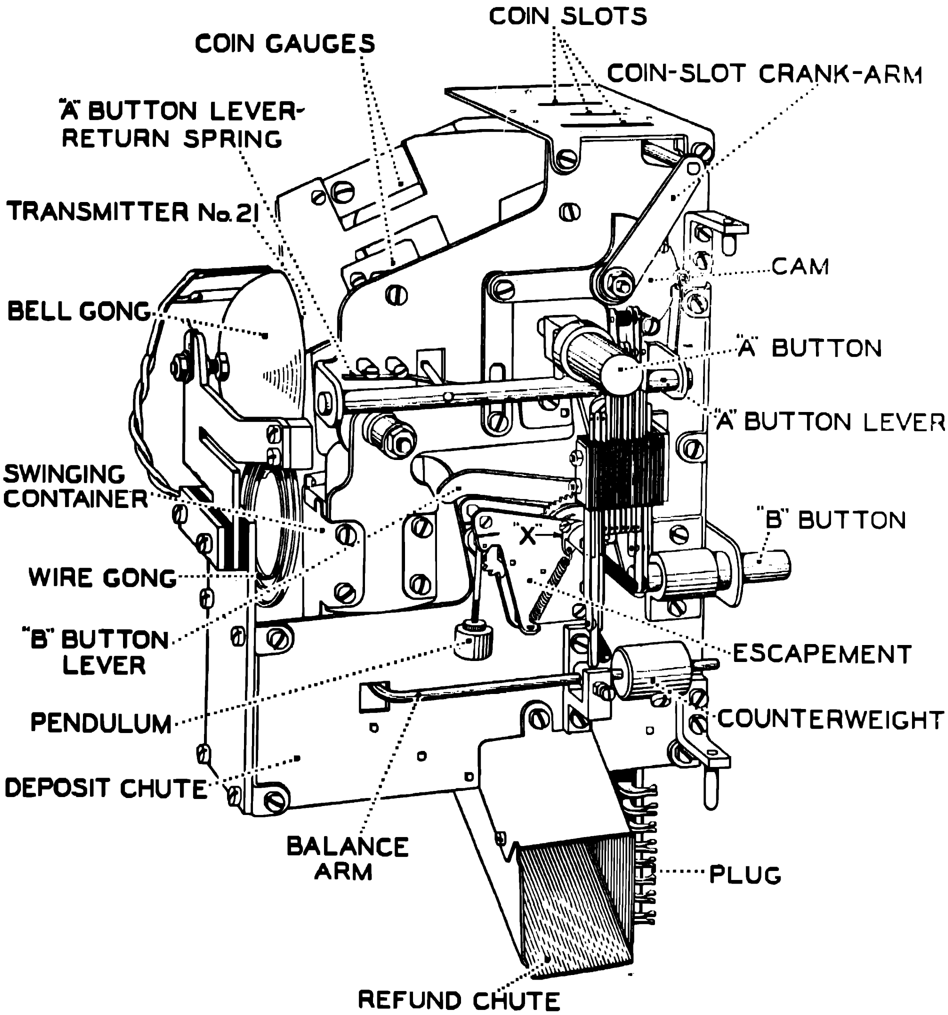


FIG. 262. PREPAYMENT COIN-BOX MECHANISM
Box, Coin Collecting No. 14.

In the buttonless type of coin-box the B button is also eliminated by mechanically coupling the pivoted coin container to the receiver switch-hook. The mechanism is arranged so that when the receiver is replaced, the coin container is swung to

the refund chute thereby returning any coins not previously deposited in the cash-box.

Prepayment C.C.B. on Automatic System. The circuit arrangements of a coin-box installation connected to an automatic exchange are shown in Fig. 263. In the normal condition the speaking and bell circuits are similar to an ordinary telephone, but the impulsing contacts of the dial are short-circuited by contact springs *CB*2 and *D*9/0. When the digits 9 or 0 are dialled the short circuit is removed at ***D*9/0** by a special cam fitted to the dial (see Chap. VIII). This enables calls to be made to the operator or emergency calls (when the facility is provided) to 999 without the prior insertion of coins.

When a local number is required, the first penny inserted operates the three ***CB*1** contacts, thus short-circuiting the speech transmitter and removing the short circuit from the coin-box transmitter (CBX). A 200 Ω non-inductive resistance is also placed in shunt with the receiver to degrade reception and to

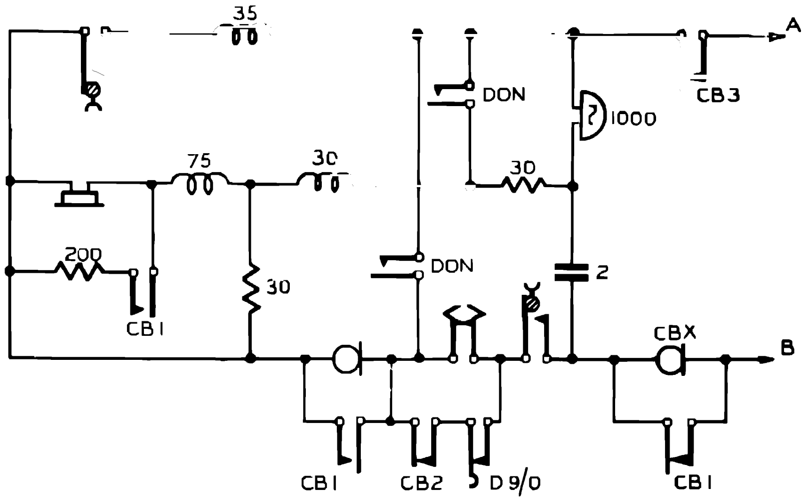


Fig. 263. Prepayment Call Office Circuit in Automatic Area

prevent the receiver from being used as a transmitter to produce false gong signals. The first penny comes to rest on the balance arm, but does not operate it. The weight of the second penny added to the first moves the balance arm which in turn operates contact ***CB*2** and removes the short circuit from the dial impulse springs. The caller is now able to dial the number required. When the called subscriber answers, the caller depresses button A which deposits the coins in the cash-box and restores contacts *CB*1 and *CB*2. Conversation can now proceed. If the call is ineffective, the caller recovers his money by pressing button B. This operation restores contacts *CB*1 and *CB*2 as when button A is depressed but also opens contact ***CB*3**. The latter are kept open for

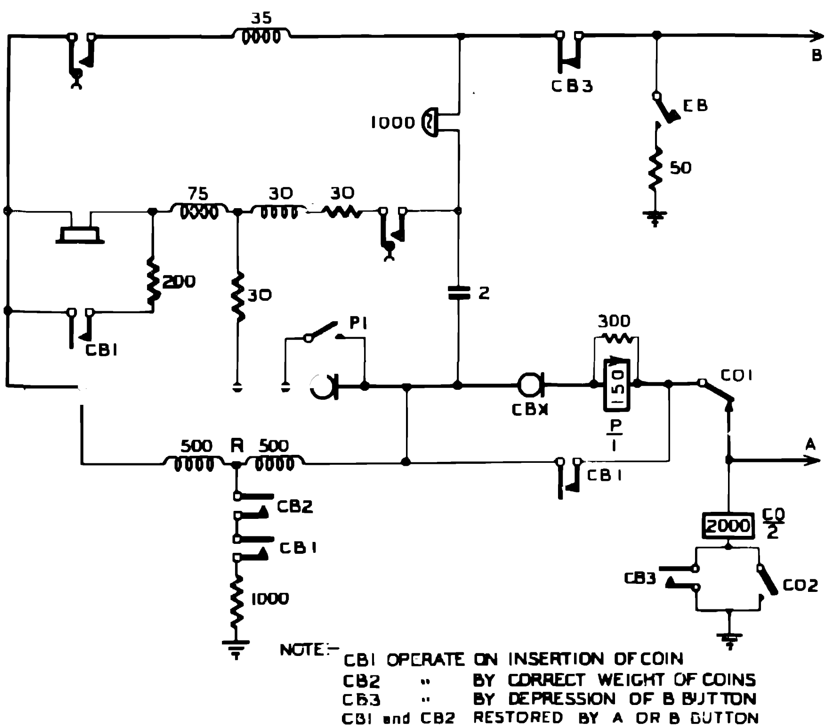


Fig. 264. Prepayment Call Office Circuit in a C.B. Area

a period of about 7 seconds by means of a clockwork escape mechanism and so ensure that any connexion set up is released.

Prepayment C.C.B. on Manual System. Additional equipment (Fig. 264) is required when a prepayment C.C.B. is used in a manual exchange area due to the need for the caller to speak to the operator before the call can be established. The line termination of a C.C.B. line at the exchange, is, as will be seen later, modified to receive an earth calling signal instead of the usual loop. The insertion of the two pennies operates contacts ***CB*1** and ***CB*2** and a high resistance earth calling signal via one 500 Ω winding of retard *R* is applied to the B-line. The polarized relay *P* is so connected that when the operator answers, the direction of the current in the line does not operate the relay. Both the coin-box and speech transmitters are therefore in circuit, and the caller can pass his request to the operator and the latter can hear the gong signals of any excess fee. The second winding of retard *R* ensures that both lines are approximately balanced to avoid noise at this stage. Special connecting circuits are provided at the exchange (see Chap. XVI) which, when connexion is made to the called party, reverse the current in the call office line. This reversal operates *P*, which in turn short-circuits the speech transmitter at ***P*1**. When the caller hears his correspondent he presses button A, which deposits the coins and by short-circuiting *P* at *CB*1 cuts out the polarized relay and coin-box transmitter. At the same time, the short circuit is removed from the speech transmitter at *P*1. Conversation can now proceed.

If the call is ineffective the depression of button B returns the coins to the caller and operates

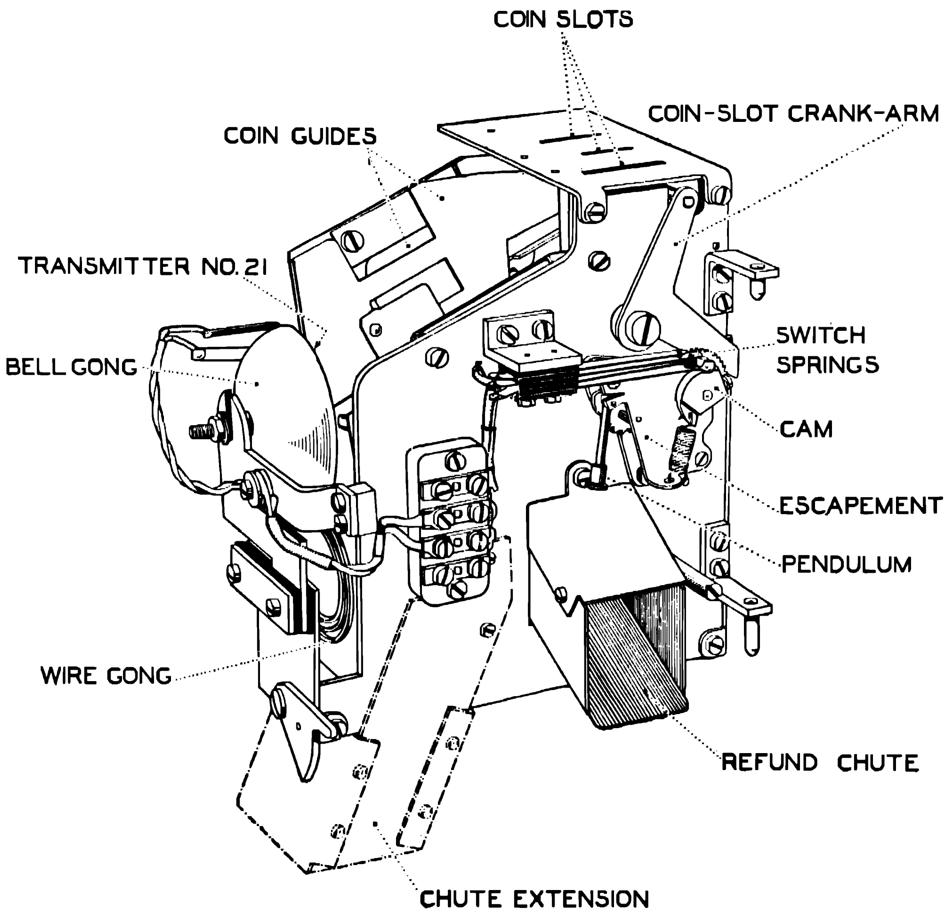
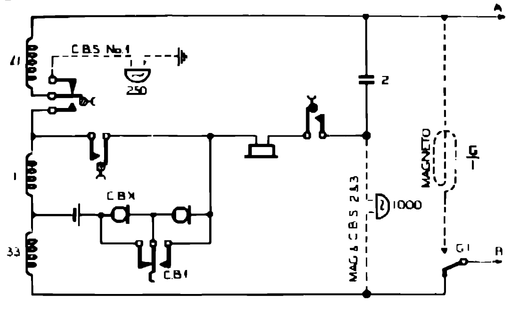


FIG. 265. POSTPAYMENT COIN-BOX MECHANISM
Box, Coin Collecting No. 16.

contacts ***CB*3**, which gives a clearing signal to the operator. If the call has been extended, one contact of ***CB*3** applies earth to relay *CO* which operates and locks via its own contact (***CO*2**) to the battery on the *A*-line. The line is now disconnected at ***CO*1** thereby giving a continuous clearing signal until the operator takes down the connexion and releases *CO*.

Emergency calls can be obtained, without the insertion of coins, by the momentary operation of the emergency button (*EB*). A low resistance earth (instead of the usual high resistance earth) is applied to the *B*-line which operates a special relay



NOTE CONTACTS CB1 OPERATE AS COIN IS INSERTED

Fig. 266. Typical Postpayment Call Office Circuit

at the exchange to give a distinctive flashing signal to the operator.

Postpayment Call Office Circuit. It is not practicable to utilize the C.B. prepayment C.C.B. circuit in any area where local battery transmission exists, owing to the insufficiency of line current to operate relays *P* and *CO*. It is, moreover, undesirable at the smaller exchanges to provide special cord circuits for coin-box lines. The postpayment coin-collecting box (Fig. 265) is based on the same general design as the prepayment type but the absence of A and B button mechanisms and the associated switching springs makes the unit much simpler. Only one spring set is associated with the box. The contacts are operated when any coin is inserted, and an escape mechanism retains the contacts in the operated position for several seconds, i.e. until the coin has passed the coin-box microphone.

A typical postpayment call office circuit is shown in Fig. 266 which indicates the several alternative connexions required for C.B.S. Nos. 1, 2, or magneto working. An outgoing call is made in the usual way and, when the operator has obtained the required subscriber, she requests the caller to insert the necessary fee. As each coin is inserted contacts ***CB*1** operate to remove the short circuit from the C.C.B. transmitter whilst the coin hits the appropriate gong. These same contacts also short-circuit the speech transmitter during this period to avoid interference with the gong signals and to prevent the production of bogus signals.

Call Office Equipment. It is important that the lay-out of equipment in a public call office should

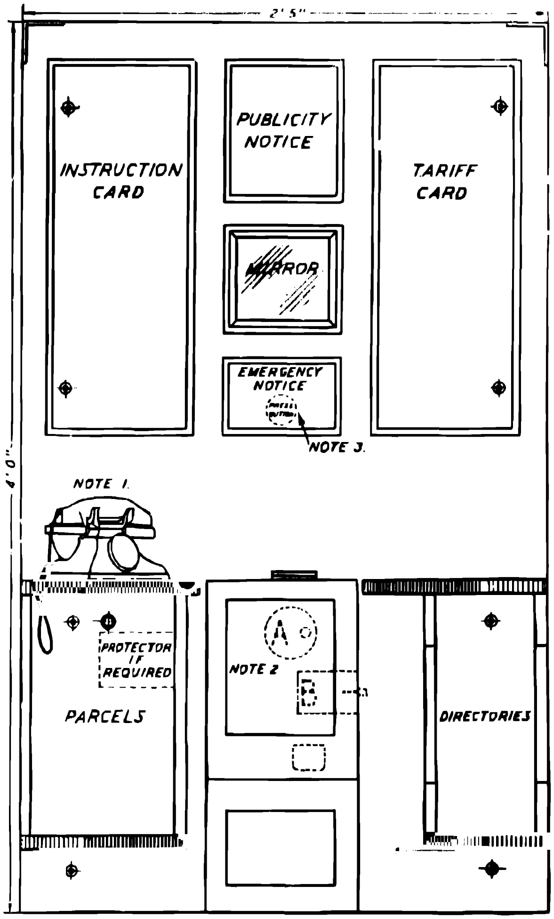


Fig. 267. Lay-out of Call-office Equipment

Note 1. Type of telephone depends on local exchange system.
Note 2. Prepayment or post-payment C.C.B. as required.
Note 3. Emergency button required only on C.B. system.

be both convenient and attractive. The very neat and pleasing assembly shown in Fig. 267 has now been standardized for all new call offices. The base of the assembly is a plywood board faced with thin black bakelite sheet. The wallboard is in two parts. The upper part accommodates the various instruction cards, etc., and a bevelled mirror which are mounted in stainless steel frames. In C.B. areas, the emergency call press button is also mounted on the upper part of the wallboard. The centre of the lower part of the wallboard is occupied by the coin-collecting box which is framed on the left and

right by receptacles for parcels and directories respectively. The tops of the receptacles are of the same bakelite faced plywood as the wallboard and, with the top of the coin-box, form a continuous shelf. The stainless steel fitments of the receptacles provide places for a cigarette or pipe and an umbrella.

The instrument is of the microtelephone type

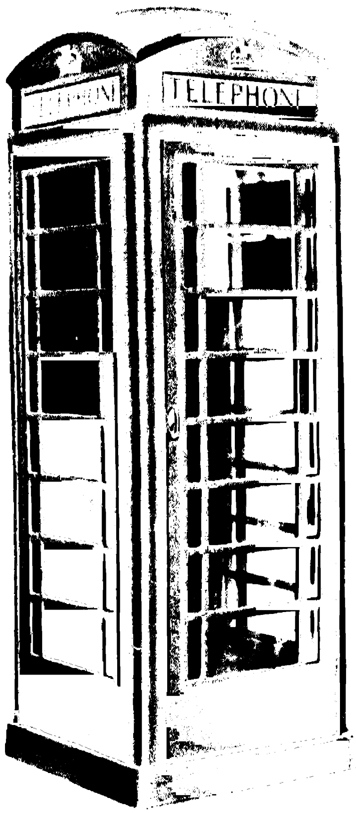


FIG. 268. STANDARD TELEPHONE KIOSK
Kiosk No. 6.

and is screwed to the top of the parcels receptacle. The cord is of the tough rubber-covered type and passes behind the wallboard to the coin-box. The induction coil, bell, relays, etc., are mounted on a metal base-plate which is placed at the rear of the coin-box mechanism. The protector and batteries when required are enclosed at the rear of the parcels receptacle behind an ebonized wood partition.

Kiosks and Cabinets. Apart from certain special cases, call offices may be installed either in existing premises by the provision of indoor cabinets or in the open by erecting suitable kiosks for the accommodation of the telephone apparatus. Cabinets provide little scope for standardization due to the different accommodation available in various offices and to wide variations in the decorative schemes. Indoor cabinets are usually of hardwood construction, although special sound-absorbing material such as prepared cork has been used for the walls of telephone cabinets. In the design of a suite of cabinets one of the major problems is to provide sufficient sound insulation coupled with the maximum degree of ventilation.

Originally telephone kiosks were of wooden construction although reinforced concrete and cast-iron assemblies have been extensively used. Reinforced concrete kiosks (P.O. Kiosk No. 3) until a few years ago were standard for urban areas. Experience has shown that concrete is difficult to obtain in standard quality and the component sections are somewhat fragile.

The standard Post Office kiosk (Kiosk No. 6) is illustrated in Fig. 268. It was designed by Sir Gilbert Scott and has been approved by the Royal Fine Arts Commission. It is constructed of some eighteen cast-iron piece parts. All parts are of the best grey cast-iron and considerable care is taken to ensure that all joints are carefully faced and fitted and all screw holes are accurately drilled to template before the assembly leaves the manufacturer's premises. To suit all conditions of use, the kiosk is made in four types, known as A, B, C, and D. All models are identical in construction except for the position of the door. The door itself is of teak and is glazed to match the side units of the kiosk. Restraining straps are fitted to prevent strain on the hinges and a special type of door closing spring is provided which gives, by means of an oil check action, a rapid closure of the door up to approximately 1 in. of the closed position and a very slow final movement which prevents slamming or shock to the kiosk assembly. The whole kiosk is painted Post Office red and the total weight without apparatus is some 13 cwt.

Kiosk Lighting. Electric light is normally provided in street kiosks whenever public supply mains are available. In some cases arrangements are made with the appropriate lighting authority for connexion to be made to the street lamp circuit so that the kiosks are automatically lighted at the same time as the street lamps. This scheme is not practicable where local time switch control of the street lights is in operation, and in these circumstances individual Venner time switches are fitted in the kiosks. A typical Venner time switch is illustrated in Fig. 269. This particular model is spring-driven, and is electrically wound every 8 h by means of a small electric motor. To guard

against stoppages due to failure of the power supply the clock is provided with three days spring storage, and should such a failure occur the clock winds itself fully immediately the supply is resumed.

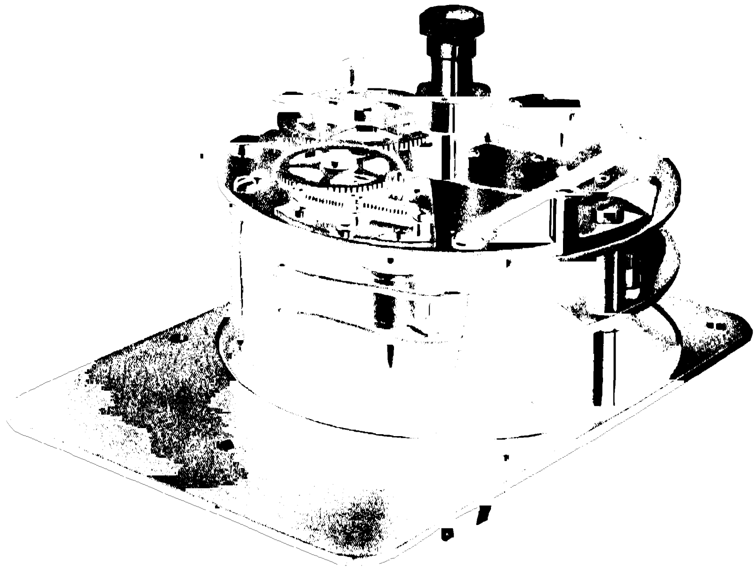


FIG. 269. MECHANISM OF VENNER TIME SWITCH

Another type of time switch incorporates a synchronous motor and this type is being increasingly used where time-controlled a.c. supply mains are available. The solar dial (Fig. 270) is a device that automatically corrects for the lengthening and shortening of the days throughout the year. It is generally adjusted to switch on the kiosk light one hour after sunset and to extinguish the light one hour before sunrise. In the British Isles ten different types of solar dial are provided to cater for the variations in solar time at different latitudes.

Lamp Calling Telephones. In certain circumstances the provision of a lamp calling signal at the telephone instrument is very advantageous. Except in special circumstances, the circuit is arranged so that the ordinary magneto bell also operates in addition to the lamp calling signal. The equipment required consists of a relay which will respond to the ringing current sent out from the exchange with a mercury tube contact to control a mains energized lamp. There are several different schemes. On an automatic system "discontinuous indication" is often adopted. With this arrangement the lamp flashes in response to the ringing current and is eventually extinguished when the ringing ceases, i.e. when the called party answers or when the calling subscriber abandons the call. In manual switching systems the relay which responds to the ringing current is arranged to lock in the operated position when it is energized. The signal lamp therefore remains alight until the locking circuit is broken either by the operation of the cradle switch when the telephone is answered or by the operation of a separate release press button associated with the relay switch.

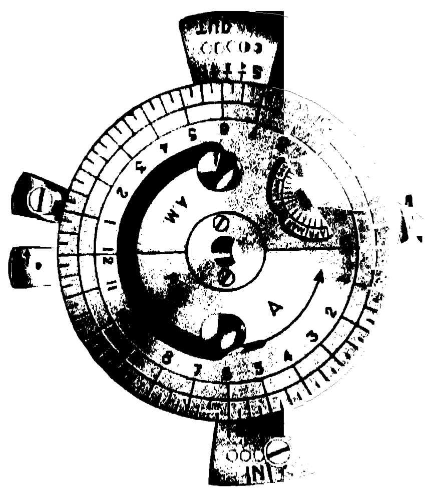


FIG. 270. VENNER SOLAR DIAL

EXERCISES IX

1. Give a circuit diagram of a subscriber's C.B. telephone set as used on a direct line to a manual exchange, and explain its operation. In what circumstances will the ringing current and voltage at the line terminals be out of phase when the bell is being rung? (*C. & G. Telephony, Grade I*, 1946.)

2. Using a simple circuit diagram, describe the operation of the telephone apparatus usually installed in a public kiosk in an automatic exchange area. (*C. & G. Telephony, Grade II*, 1943.)

3. Describe the construction of a modern table type instrument with a combined handset. Give simple sketches and explain the action of an interlocking key unit for use with the telephone.

4. Discuss the requirements for telephones to be installed in situations where inflammable gases may be present.

5. Give a diagram of the wiring arrangements of a Plan 1A installation with a main station and two extensions. Is there any theoretical limit to the number of extensions on a Plan 1A installation?

6. Draw a diagram of a telephone circuit suitable for use as the extension instrument of a Plan 1 installation in an automatic area.

7. Describe the facilities provided in an arrangement of subscribers' apparatus consisting of a "main" instrument and one "extension" instrument, with intercommunication between them. Show, by means of schematic diagrams, the different circuit connexions when the 4-position switch associated with the main instrument is in each of its four positions. (*C. & G. Telephony, Grade II*, 1946.)

8. A subscriber on an automatic exchange requires to make frequent calls to some forty regular numbers. Describe a mechanism which would be advantageous in such circumstances.

9. Describe a prepayment type of coin-box mechanism. What safeguards are provided to prevent fraud?

10. Describe the construction and equipment of a modern telephone kiosk.

CHAPTER X

THE PRINCIPLES OF MANUAL SWITCHING

THE first telephones installed were for the purpose of communication between two fixed points, as for example between the manager's office and the workshop. Such installations are now known as *private wires* or *house telephones*, depending upon whether or not they involve the use of external connecting wires. It was soon realized that the utility of the telephone would be greatly enhanced if a means could be devised whereby any instrument could be connected at will with any other instrument in the neighbourhood. For this to be possible, it is necessary either to run wires between each and every telephone in the district—an obviously impracticable scheme—or alternatively to connect all the telephones to some common point at which the necessary connexions can be made. The choice of a location for the connecting point is the first economic problem of telephone switching, since the site must be so chosen that the aggregate cost of all lines connected to it is a minimum. In general, this theoretically best switching point is very roughly at or near to the geographical centre of the area to be served, but it is a problem which requires detailed consideration and analysis.

The office or building chosen for the interconnexion of telephones naturally became designated a *telephone exchange* or merely an *exchange*. The users of the telephones connected to an exchange paid a periodical subscription for the service they received, and hence they came to be known as *subscribers*. The person originating a call is referred to as the *calling subscriber*, whilst the person for whom a call is destined is known as the *called subscriber*. Equipment is necessary at the exchange for the termination of all lines and for interconnecting the lines as required. Originally, and indeed to a considerable extent to-day, oral instructions were given as to the connexions to be made and the required switching was effected by hand. Such exchanges are known as *manual exchanges* to distinguish from *automatic exchanges* in which the switching of one subscriber to another is done mechanically without the intervention of human aid at the exchange. Automatic exchanges are considered later in Volume II and this chapter is therefore primarily devoted to the principles of manual switching.

The Switchboard. In a manual exchange the means provided for the interconnexion of the lines terminated therein is known as a *switchboard*. The staff of the exchange responsible for establishing the connexions between subscribers are known as *telephonists* or *operators*, and the part of a switchboard normally controlled by one operator is known as an *operator's position* or simply as a *position*. For structural and installation reasons it is desirable to design a switchboard as a series of separate units assembled together as required. Such units

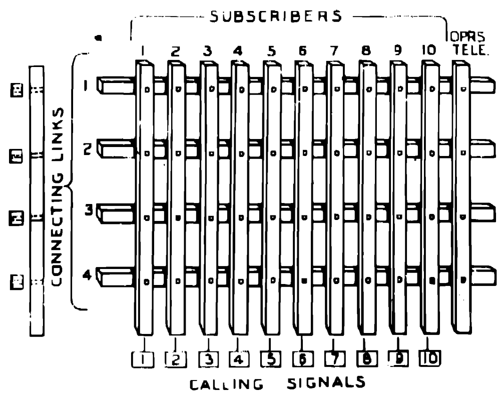


FIG. 271. ELEMENTARY CROSS-BAR SWITCHBOARD

are termed *switchboard sections* and each may consist of one or more operators' positions. A series of sections assembled together is known as a *switchboard suite*.

Cordless Switchboards. The earliest designs of switchboard were based on the principle shown in Fig. 271. The subscribers' lines (a single conductor and an earth return were first used) were terminated on vertical brass bars, slightly behind which a number of horizontal bars were arranged so as to include the whole of the subscribers. Holes were provided in the bars so that any subscriber's line could be connected to any other line via one of the horizontal connecting bars by the insertion of metal pegs at the appropriate points. One vertical bar was usually connected to the operator's telephone instrument so that she could ascertain the number required by the subscriber and, when connexion had been established, could supervise the call.

The growth in the number of subscribers and the advent of two-wire circuits made the simple cross-bar arrangement very cumbersome, and means were evolved whereby any line could be associated

with any of the connecting circuits without the necessity of providing bulky bars along the face of the switchboard. The subscribers' lines and the link circuits were terminated on the tags of a number of connecting springs so arranged that a subscriber's line could be extended to a link circuit

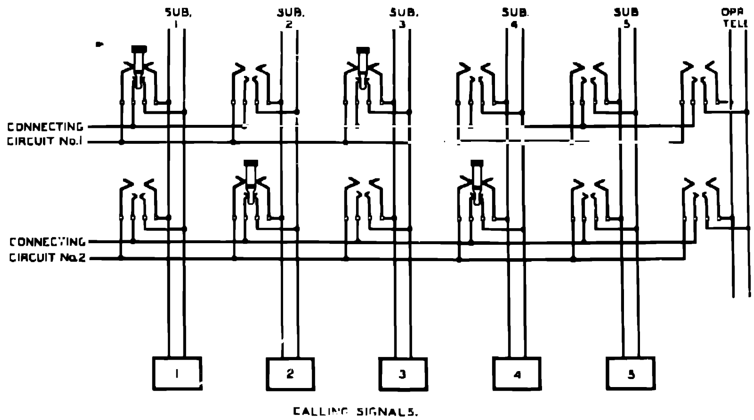


FIG. 272. CORDLESS SWITCHBOARD USING PEGS AND JACKS

by the insertion of a metal *plug* into the appropriate *jack*. This arrangement is indicated in Fig. 272, which shows the switching conditions for five subscribers' lines requiring two connecting circuits. Plugs are shown connecting subscribers 1 and 3 via circuit No. 1, and 2 and 4 via connecting circuit

circuits are sufficient for the maximum number of simultaneous conversations of, say, 100 subscribers, a total of 1500 jacks are required; but if the number of subscribers is doubled (i.e. 200) then the number of jacks required is 6000. The number of jacks required does, in fact, increase as the square of the number of subscribers. It is for this reason that *cordless switchboards*—as they are generally classified—are impracticable for public exchange use. Nevertheless, variations of this same principle using lever keys instead of jacks are used extensively for private branch switchboards where the number of lines does not exceed twelve. For such purposes the cordless switchboard has valuable advantages due to the absence of flexible conductors with the consequent reduction of maintenance charges. The modern variation of Fig. 272 is shown in Fig. 273. Three-way lever type keys are used, each enabling a line to be switched to one of two connecting links. Apart from the saving of space by the introduction of keys, the fault liability is very much less than any arrangement employing plugs and jacks.

Cord Type Switchbobrds. Flexible connecting

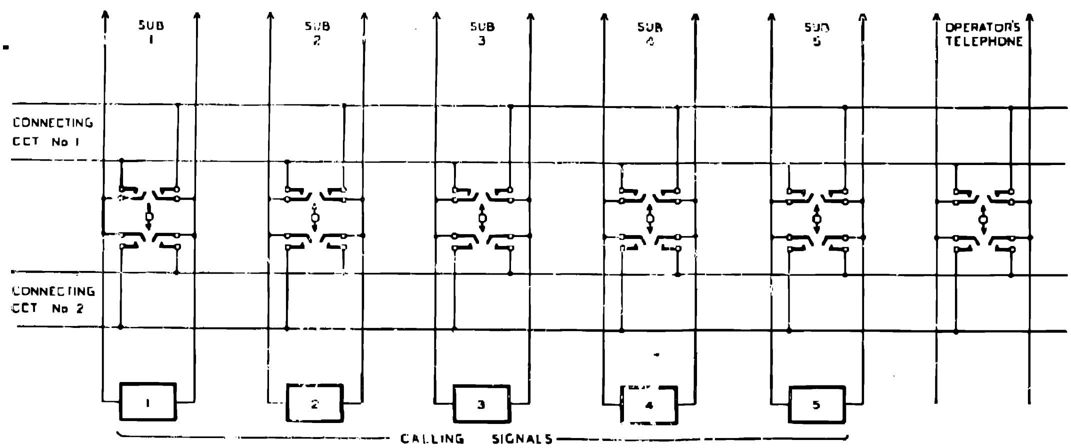


FIG. 273. CORDLESS SWITCHBOARD WITH KEY SWITCHING

No. 2. Whilst the use of jacks greatly reduces the switchboard space required (ten small jacks replace the five vertical and two horizontal pairs of bars), it is apparent that, as the number of subscribers increases the number of jacks required grows enormously. For example, if fifteen connecting cords are now universally used on all manual switchboards except for those of the smallest type. Fundamentally a cord type switchboard can be arranged by terminating each subscriber's line on a pair of connecting springs with which is associated a calling indicator or lamp. Jacks of any two

subscribers' lines may be connected together by means of a flexible cord terminated at each end on a metal plug designed to engage with the springs of the jacks (Fig. 274). With this simple scheme,

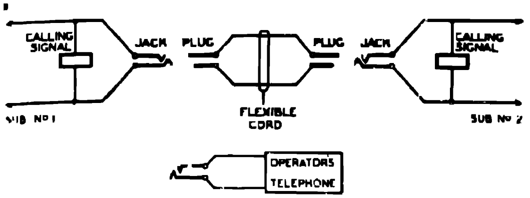


FIG. 274. SWITCHING BY MEANS OF DOUBLE-ENDED FLEXIBLE CORDS

however, three consecutive operations are involved before a call can be established, viz.:

(*a*) The calling subscriber must be connected to the operator's telephone jack in order that the operator can ascertain the number required.

(*b*) The called subscriber must be connected to the operator's telephone in order that he can be rung.

(*c*) The calling and called subscribers must be connected together for speaking.

This operating procedure is very cumbersome and, moreover, it does not provide for the operator to supervise the progress of the cali once the connexion has been set up unless she withdraws one of the plugs and so interrupts the conversation.

Single Cord Switchboards. An arrangement similar to that shown in Fig. 275 has been used in the past for small magneto switchboards. In addition to the subscriber's jack, each line is also terminated by a single cord and plug. Such switchboards are known as *single cord switchboards*. On receipt of a calling signal the operator places the plug of the calling line into the jack associated with her instrument. After ascertaining the number required, she inserts the plug connected to her telephone into the jack of the required line. Finally, after ringing the called subscriber, the plug of the required line is inserted into the jack of the calling line, thereby establishing connexion between the calling and called subscribers. The operator can supervise the progress of the call at any time by inserting her instrument plug into the free jack of the called line. This arrangement is not applicable to large exchanges and, even for small switchboards, it has no particular merits over the cordless type except possibly in respect of initial cost. The single cord principle has now been entirely superseded by the cordless type of switchboard on account of the lower liability to faults of the latter.

Double Cord Switchboard. All modern exchanges which are too large for the application of the cordless method of switching, employ the double cord principle illustrated in Fig. 276. Two separate plugs and cords are connected together through a *cord circuit*. The same cord of a pair is always used for answering a calling subscriber and the other for connecting to the called subscriber,

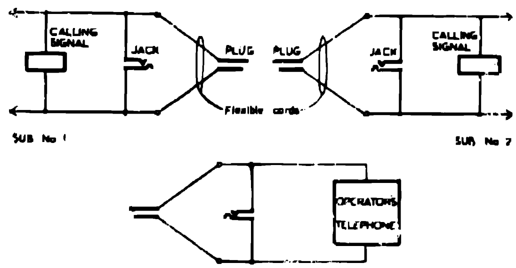


FIG. 275. PRINCIPLE OF A SINGLE CORD SWITCHBOARD

and hence they are referred to as the *answering cord* and the *calling cord* respectively. Keys are provided in the cord circuit which enable the operator to speak and listen to either subscriber and also to ring the called subscriber. Usually the *speaking* and *ringing keys* are combined into one unit so that when the key is thrown in one direction the operator can associate her telephone with the connexion, and when it is thrown in the other direction she can ring the called subscriber. Additional keys, known as *ring-back keys*, are sometimes provided to enable

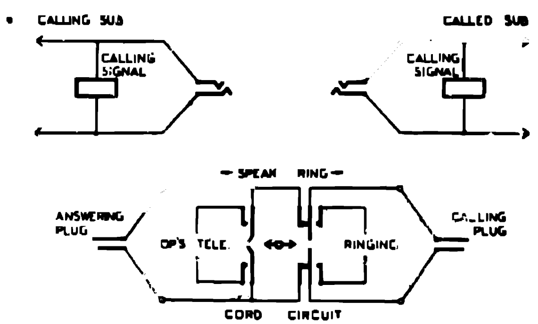


FIG. 276. DOUBLE CORD SWITCHBOARD WITH CORD CIRCUITS

the operator to recall the originating subscriber should this be necessary. The ring-back keys may be provided on the basis of one per cord circuit or, alternatively, a common ring-back key may be inserted in the speak key commons so that it can be associated with any cord circuit at will.

On receipt of a calling signal the operator inserts the answering plug of a convenient cord circuit into the line jack of the calling subscriber. She then throws the speak key and, after ascertaining the number required, places the calling plug of the

same cord circuit into the jack of the required line. The called subscriber is rung by the operation of the cord circuit ring key and, when the call is established, the operator can monitor or supervise the call at any time by throwing the speak key.

Cord Circuit Supervisory Signals. In the switching schemes so far considered no visual signals have been provided to inform the operator when the connected parties have finished their call. Such answering and calling cord supervisory signals. On all modern systems the clearing signal is a disconnexion of the subscriber's loop, hence the cord circuit supervisory signals are energized for so long as the subscribers' receivers are off the rest, and are released when the calling and called subscribers replace their receivers. This form of supervisory signal is known as *negative clearing* and does not give so forceful an indication to the operator as a

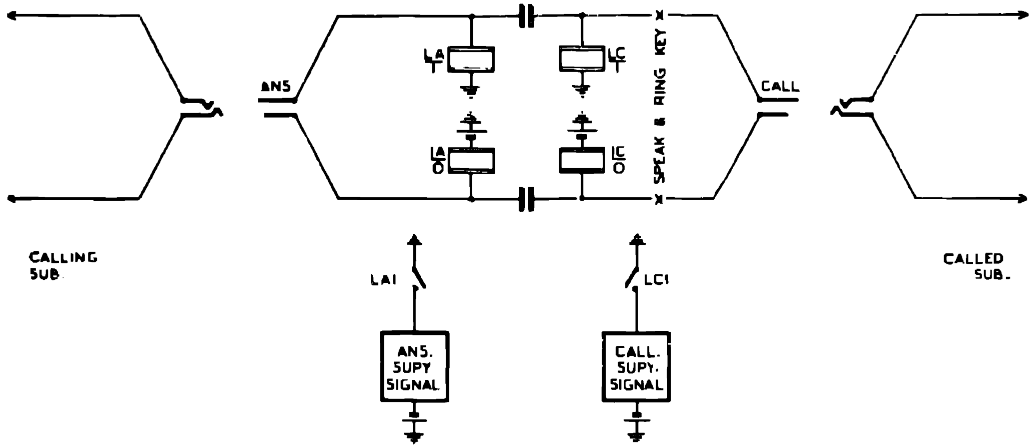


Fig. 277. Bridge Control Cord Circuit with Negative Supervisory Signals

signals are known as *supervisory signals*. On the smaller switchboards it is often possible to arrange that the calling indicator shall also serve as a supervisory signal when the subscriber hangs up his receiver. In some instances, however, the signalling conditions do not permit of this and, in any case, it is impracticable in a large exchange to place the supervisory signals along with the subscribers' jacks. The usual arrangement is to associate the supervisory signals with the calling and answering cords.

In a manual exchange there are considerably fewer cord circuits than subscribers' lines. It is therefore obvious that the transmission bridge required during the progress of a call and the signalling relays or indicators for supervision purposes should be associated with the cord circuit rather than with the line termination.

The Bridge Control System. A manual switching system where the transmission bridge and signalling relays are included in the cord circuit is known as a *bridge control* system. The principle is illustrated in Fig. 277. A simple condenser-impedance bridge is shown between the answering and calling cords. The impedance coils (*LA* and *LC*) connected to the tip conductor of the cord circuit are in the form of relays, the contacts of which control the scheme in which the supervisory signal is operated only at the *end* of the conversation.

The negative clearing system of Fig. 277 can be converted to a *positive clearing* scheme by the introduction of a third connexion on the plugs and jacks. The contacts of relays *LA* and *LC* are now arranged (Fig. 278) either to disconnect or to shunt the supervisory signals whilst the conversation is in progress, but at the end of the call the restoration of *LA*1 and *LC*1 completes the circuit for the clearing signal via the third conductor of the plugs and jacks to an earth in the line termination. By this arrangement, the supervisory signal is operated when the subscriber hangs up his receiver, and remains operated until the telephonist withdraws the plug from the jack. The positive clearing system is now standard for all public exchanges where a supervisory relay is provided. If, for sake of economy, the cord circuit supervisory indicator is placed directly in the cord circuit, positive clearing is not possible with standard disconnexion clearing from the subscriber.

The Sleeve Control System. The arguments for the placing of the transmission bridge and signalling relays in the cord circuit rather than in the line termination do not apply in the case of automanual and trunk exchanges. On such switchboards, the

number of lines terminated on the manual board is considerably less than the total number of subscribers which they serve. The number of circuits is, in fact, determined wholly by the anticipated volume of simultaneous calls. Moreover, when a large number of calls are routed over junction and trunk circuits, the signalling relays in the cord circuit are required to function correctly over wide ranges of line resistance and with a number of different systems of junction signalling. Until some fifteen years ago all trunk exchanges were of the bridge control type, and it was then necessary to have a number of different types of cord circuit on each operator's position to meet the individual signalling requirements of the various trunks and junctions. There were a number of other complications, particularly the difficulty of arranging for team working between operators.

In view of the signalling difficulties, all automanual and trunk switchboards are now designed with the signalling relays and transmission bridge in the line termination, the cord circuit being merely a pair of speech conductors void of all signalling apparatus. Since the cord circuit supervisory signals are associated with the cord circuit and not with the line termination it becomes necessary with this system to pass the clearing signal from the line termination to the cord circuit via the third conductor of the connecting plug and jack. It is for this reason that the method is known as the *sleeve control system*. The principle is illustrated in Fig. 279, which should be compared with the comparable bridge control arrangement shown in Fig. 278. Relay *LA* is operated for so long as the calling loop is maintained, but at the end of the conversation *LA* releases and *LA1* completes the circuit via the bush of the jack and the sleeve of the plug to operate the answering supervisory signal. Similar arrangements exist on the calling side of the cord circuit. It will be noted that two transmission bridges are now required per connexion as compared with the single bridge in the cord circuit of the bridge control system. This is a slight disadvantage from an economics point of view but the great benefits of permanently associating the supervisory relay with the line and the simple and universal cord circuit more than outweigh the small additional cost. The association of the transmission bridge with the line termination has also some tranmissions advantages on amplified trunk and junction circuits.

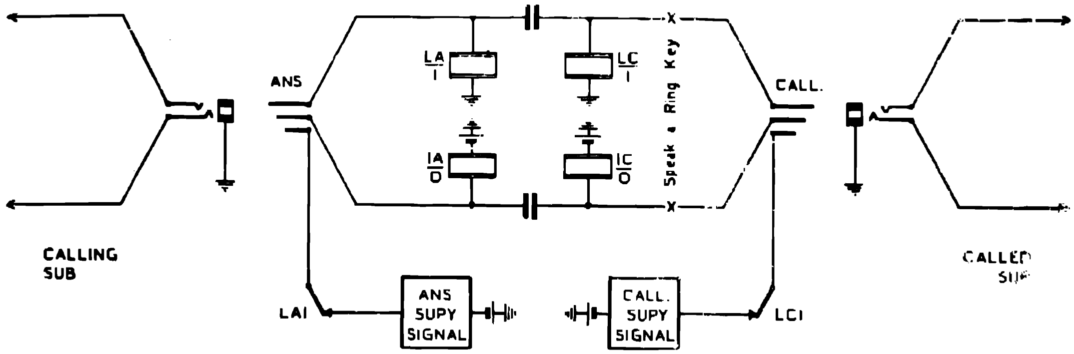


FIG. 278. BRIDGE CONTROL CORD CIRCUIT WITH POSITIVE CLEARING SIGNALS

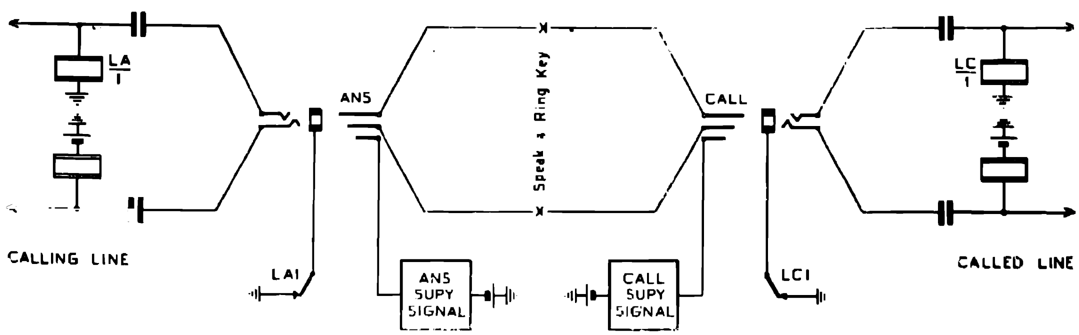


FIG. 279. PRINCIPLE OF THE SLEEVE CONTROL SYSTEM

The terms "bridge control" and "sleeve control" are perhaps somewhat confusing. It is apparent from the foregoing considerations that the supervisory signals are in both cases controlled from relays associated with the transmission bridge. Moreover, the sleeve connexion is an essential link for the control of the positive clearing signal of the

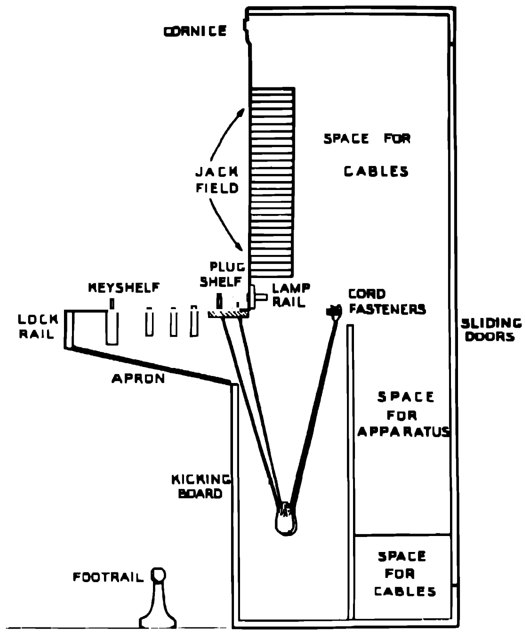


FIG. 280. CROSS-SECTION OF TYPICAL MANUAL SWITCHBOARD

bridge control system (Fig. 278). The reader should therefore realize that the sole difference between the two systems is that in the bridge control system the supervisory relays are in the cord circuit, whereas in the sleeve control system the supervisory relays are in the line termination and the cord circuit supervisory signal is controlled from the line termination via the sleeve conductor of the plug.

Switchboard Design. Whilst differing considerably in detail, most modern switchboards have the same fundamental arrangement of equipment and have the same general appearance. Fig. 280 shows a sectional view of a typical switchboard, whilst Fig. 281 gives a front view of the same board. Earlier switchboards were constructed almost entirely of wood, but it is now the general practice to make the framework of steel with an exterior finish of mahogany or other hard wood. Teak is often specified for use in the tropics owing to the ravages of white ants and other wood pests. The horizontal shelf, which in modern boards is placed at a standard height from the floor, is known as the *keyshelf* since it was first used purely for the accommodation of the speaking and ringing keys, but nowadays it has in addition a variety of other keys, supervisory equipment, etc. The keyshelf may be considered as the control panel of the position.

The rear portion of the keyshelf is reserved for the connecting cords which are normally arranged in pairs with the calling plug in front and the answering plug behind. Each plug rests vertically in a socket in the *plugshelf* with the cord passing through a hole in the shelf. The cords are passed round a weighted pulley and are terminated on suitable *cord fasteners* for connexion to the cord circuit. This arrangement ensures that the cords are stored safely away when not in use, and the gravitational pull of the pulley weights maintains the cords taut when in use in addition to restoring the plugs to their normal position when they are withdrawn from the line jacks.

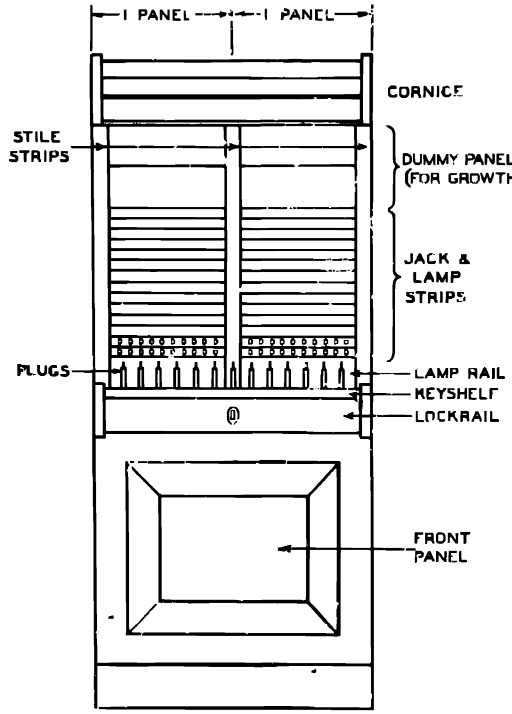


FIG. 281. FRONT VIEW OF TYPICAL MANUAL SWITCHBOARD

The key and plug shelves are subject to very hard usage and on the latest boards are faced with red fibre, since it is found that this material maintains its appearance better than the polished wood of earlier designs. The keyshelf is hinged along its back edge so that it can be raised from the front to

allow maintenance of the keyshelf equipment and wiring. The narrow panel supporting the keyshelf along its front edge has, from the earlier practice of locking the keyshelf, become known as the *lock rail* and is now used to house the operator's instrument jack. The under-side of the key and plug shelf is closed by a sheet iron *apron,* whilst the face of the switchboard below the keyshelf is provided with decorative panels which can be removed when desired. The height of the keyboard usually necessitates the use of correspondingly high chairs, and a wooden *foot rail* of circular section is provided for the operator's feet. Damage to the front panels is prevented by the insertion of a leather panel (the *kicking board*) immediately behind the foot rail. Similarly, there is a tendency for the pulley weights to hit the back of the front panels if a cord is violently withdrawn and to prevent noise due to this cause the back of the panels are often covered with felt.

The face of the switchboard above the keyshelf is broadly known as the *jack field,* and it accommodates, as well as the line jacks, the subscribers' calling indicators or lamps. In general when indicators are used they are grouped together in the jack field with the subscribers' and other jacks above or below them. When, however, lamp signals are used they are usually mounted immediately above the jack to which they refer. The jack field is divided into vertical strips or *panels* by means of flat steel bars known as *stile bars.* The panels are of uniform width and are designed to hold strips of jacks, lamps, or indicators placed horizontally between the stile bars. Single position sections usually have two panels, but it is not necessary that there should be an exact number of panels per position especially when several positions are constructed together to form a section.

The jack, lamp, and indicator strips rest one on top of the other and are fastened from the rear to the stile bars by *jack fasteners.* The steel stile bars themselves are covered at the front by *stile casings* or *stile strips* which are used to hold suitable labels (or are engraved) to designate the various groups of jacks, etc. The extreme bottom of the jack field lies behind the plugs and hence cannot be used for jacks or indicators. A blank panel is therefore inserted at this point but in some cases it provides accommodation for various miscellaneous lamps and it has become generally known as the *lamp rail.*

The jack field is surmounted by a decorative *cornice* which in some cases is partially removable to provide additional jack capacity. The roof and rear doors (the latter are usually of the sliding or lift-out type to economize in space) are of steel in order to minimize the risk of fire, and on account of cost.

The internal arrangements of a switchboard are determined largely by the type of board and the system employed. In general, the space behind the jack field is taken up by the cables to the jacks, etc., whilst that behind the cords is used to hold apparatus associated with the cord circuits.

From what has already been said it is apparent that keys, plugs, cords, and jacks are the elementary components of any manual switching system and more detailed consideration of the design of these items is desirable at this stage.

Switchboard Cords. Flexible switchboard cords represent possibly the weakest link in a telephone system, since from the very nature of their employment they are subjected to continual twisting and bending. It is found in practice that faults very rapidly develop at the point where the cord is joined to the connecting plug. Considerable experimental work has been done in an effort to produce a satisfactory cord with long life, and the type illustrated in Fig. 282 is now standard for all switchboards. In this cord, each conductor contains some twenty-six strands of tinsel thread, each thread consisting of a tough copper or bronze ribbon, spiralled upon a mercerized cotton centre thread. The tinsel conductor is served with two close lappings of silk or rayon and is covered with a soft cotton braiding. In a three-conductor cord, the colours of these braidings are white, blue, and red. The three insulated conductors are spiralled together and are made up to circular cross-section with three soft cotton wormings. The cord is completed with a final lapping of cotton and an externally glazed cotton braiding. In joining up switchboard cords, the white-covered conductor is invariably connected to the tip, blue to the ring, and red to the sleeve of the plug.

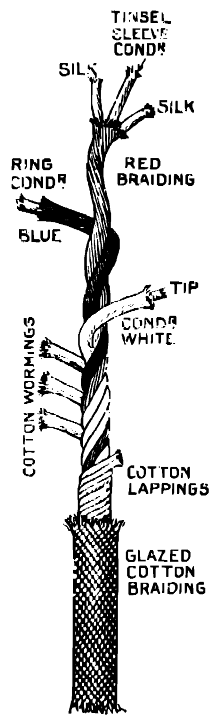


FIG. 282. DISSECTED THREE-WAY SWITCHBOARD CORD

Pulley Weights. A cord pulley suitable for use in small and medium sized switchboards is shown at the right of Fig. 283. It consists of a brass pulley, through which the cord is threaded, weighted to

about ½ lb with lead. With such a single pulley, the maximum length of a cord is somewhat less than twice the distance from the floor of the switchboard to the plugshelf. Cords for use with this type of pulley are, in fact, usually 72 in. long. In larger switchboards and on certain positions (notably end positions) of other exchanges, longer cords are required to reach all the jacks, and a double pulley as shown on the left of Fig. 283 is employed. With

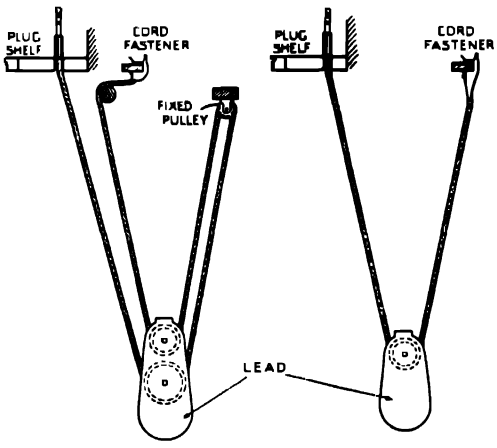


FIG. 283. DOUBLE AND SINGLE PULLEY SYSTEMS OF WEIGHTING SWITCHBOARD CORDS

double pulley weights, used in conjunction with a fixed pulley arranged as shown, it is possible to fit cords up to 117 in. long in switchboards having the plugshelf 3 ft. from the floor.

Colour Schemes. To enable operators to trace cords easily and so to reduce the probability of a wrong plug being removed from a jack, it is usual to employ a colour scheme. Cords with braidings of black, red, green, yellow, blue, and neutral are available, and different combinations of these colours are used on switchboard positions of various types. In small exchanges where it is not economical to maintain a stock of a large number of colours, the cords are usually black and red alternately.

Cord Tags and Fasteners. The connexion of switchboard cords to the permanent wiring of the position is effected by means of tinned copper cord tags which are attached to suitable cord fasteners. It is not practicable to solder tags to the tinsel conductors of a cord, owing to the presence of the mercerized cotton core which would char under the heat of a soldering iron. The cord tags are clamped during manufacture to the tinsel conductors of the cord by means of a special tool, and in practice it is rarely necessary to repair this end of the cord during its useful life. As in all other instances, care must be taken to prevent mechanical stress on the connecting tags of a cord and a special lace is formed by the plaiting of the outer braiding. The lace is tied to a ring near the cord fasteners so as to prevent pull on the cord conductors themselves. The fasteners by which the cord is connected to the permanent wiring must provide an efficient and durable connexion, but at the same time must readily allow the replacement of any individual cord. On earlier switchboards, the cord tags were of the pin type and a spring-loaded connector was fitted on the switchboard. Whilst this method was very convenient for the changing of cords, it was found by experience to be unreliable. Nowadays cord tags are always of the forked type and are connected to tags by means of cheese-headed screws. The tags in turn are mounted on a wooden rail which runs the length of the position, separate rails usually being provided for the cords serving the back and front rows of plugs.

Plugs. Switchboard plugs are invariably of the two-way or three-way type, depending upon whether two or three connexions are to be made. Various views of a simple two-way plug are shown in Fig. 284. The metal parts of the plug are made of brass, and the insulation employed is ebonite, whilst the cover or handle of the plug is usually of red or black fibre. For identification purposes, the two connexions of the plug are referred to as the *tip* and *sleeve*—terms which are self-explanatory from an examination of the illustration. Two-way plugs are seldom used nowadays, except in old type switchboards and possibly on modern boards of very small size. As will be seen later, most systems

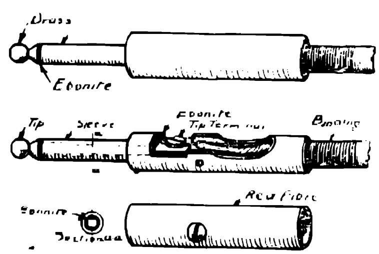


FIG. 284. DETAILS OF A TWO-WAY SWITCHBOARD PLUG

require that three connexions shall be made and hence three-way plugs, in conjunction with three-conductor cords, are usual. The three-way plug (Fig. 285) is similar in design to the two-way plug, but has, in addition, a *ring* connexion, placed between the tip and sleeve. In most modern switching systems it is desirable that the tip and ring conductors of a plug should not be short-circuited by contact with the jack springs when a

plug is being inserted into a jack. A thick insulated metal collar (Fig. 286) is introduced between the tip and ring, and the dimensions are such that the collar effectively shields the ring until the plug is

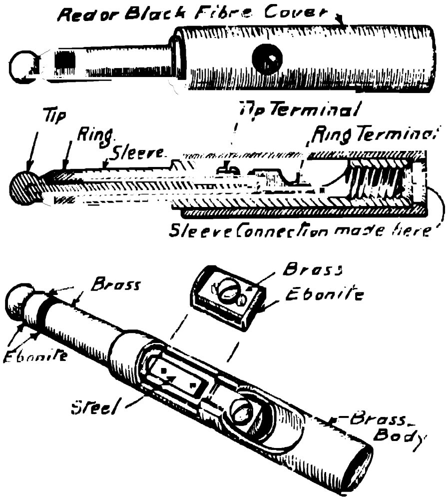


FIG. 285. DETAILS OF THREE-WAY PLUG

fully inserted. Fig. 286 also shows the method of terminating a switchboard cord in its plug. The tip and ring conductors of the cord (white and blue respectively) are terminated by small tags which

colour plugs are available for use in special circumstances where it is necessary to differentiate between the various cord circuits on one position.

In addition to switchboard plugs there are of course numerous plugs of special design employed in telephony. The operator's instrument plug is of interest and is illustrated in Fig. 288. The plug is

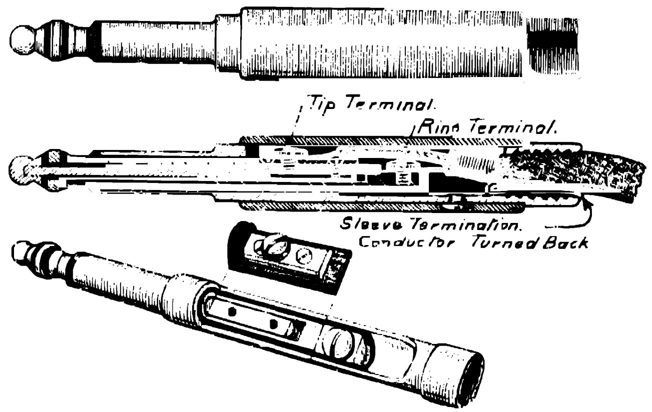


FIG. 286. DETAILS OF THREE-WAY PLUG WITH GUARD COLLAR

of more substantial construction than the switchboard plugs previously described since the space required by the associated jack is not of vital importance. The four connexions of the plug link

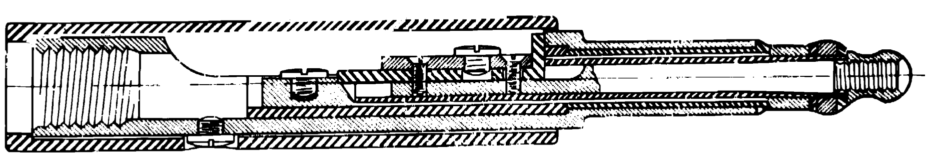


FIG. 287. CROSS-SECTION OF MODERN SWITCHBOARD PLUG WITH FULLY INSULATED SLEEVE
Plug No. 316.

are squeezed by a suitable tool to grip the tinsel conductors. The tags in turn are screwed to their respective parts of the plug. The sleeve conductor (red) is not tagged, but the bared tinsel is turned back over the prepared end of the braiding and the latter is screwed tightly into the sleeve of the plug. In the more modern automanual switchboards, one or two relays of high inductance are included in the sleeve circuit. This, together with the high voltage employed, has resulted in electric shocks to the operators due to the exposed sleeve of the plug. A plug (Plug No. 316), with a completely insulated sleeve, has been introduced to avoid shocks and is now standard for all exchanges where the voltage is in excess of 40 (Fig. 287). Normally all plugs are fitted with red covers, but cerise, black, and neutral

the operator's transmitter and receiver (Fig. 289) to the position telephone circuit, and the plug is so dimensioned that there is no risk of short-circuiting



FIG. 288. OPERATOR'S INSTRUMENT PLUG
Plug No. 404.

the battery supply or of applying a demagnetizing direct current to the receiver if the plug is only partially inserted.

Jacks. By definition, a jack is any device used for terminating the permanent wiring of a circuit and

which provides for connexions to be made by the insertion of a suitably designed plug. Jacks are termed *two-point*, *three-point*, *four-point*, etc., in



FIG. 289. OPERATOR'S BREASTPLATE TRANSMITTER AND HEADSET

accordance with the number of connexions with which they are provided. In general, switchboard jacks may be divided into two main classes:

(*a*) *Branching jacks* where the insertion of a plug merely makes contact with the springs of the jack.

(*b*) *Break jacks* where the insertion of a plug not only makes contact with the line springs but also breaks the normal circuit through the contacts of the springs.

In addition, jacks of either type may be provided with *auxiliary contact springs* which are operated by the movement of the line springs on the insertion of a plug. Whilst individual single jacks are used at various points for miscellaneous purposes in an exchange, the jacks used for the termination of subscribers' lines are invariably provided in strips of ten or twenty jacks. Strips of ten jacks are employed if the type of jack has break contacts or auxiliary springs, and also with straightforward three-point jacks if a designation label is required adjacent to each jack. In all other circumstances strips of twenty jacks are used. Fig. 290 shows a typical strip of ten break-type jacks, whilst Fig. 291 shows how the circuit to the inner springs is disconnected on the insertion of a plug. Fig. 292 shows an eight-way jack of the break type with three auxiliary springs which change over when a plug is inserted. A portion of a strip of three-point branching jacks of a small type is illustrated in Fig. 293, whilst Fig. 294 shows a plug inserted in the jack. Apart from the jacks required for the termination of lines, strips of special two-way jacks are provided to accommodate signal lamps (Fig. 295).

Gauges of Jacks. In general, switchboard jacks are designed so that they occupy a minimum of space consistent with sufficient mechanical strength and reasonable freedom from wiring congestion. The space requirements on a small switchboard are, however, not so severe as in a large exchange, and hence larger and more robust plugs and jacks may

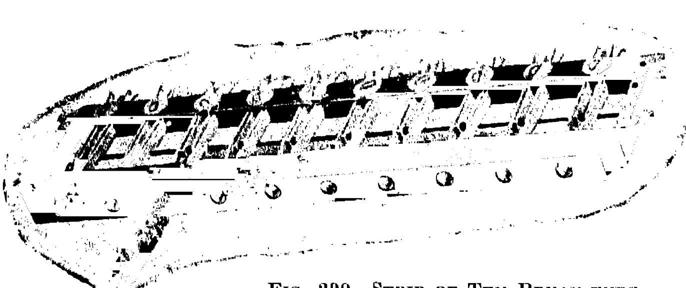


FIG. 290. STRIP OF TEN BREAK-TYPE SWITCHBOARD JACKS

be used in the smaller exchanges. Jacks of various gauges have been produced in the past and, for identification purposes, an index letter is used in

the Post Office to indicate the gauge of a plug or jack. The "B" gauge with a sleeve diameter of 0·252 in. is probably the most common size and is standard for all new equipment. The "C" gauge

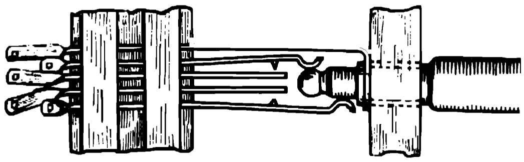


Fig. 291. Plug Inserted in Five-point Break-Jack

(0·208 in.) is the smallest size and has been used extensively at C.B.1 exchanges where the space factor is of some importance.

Mounting of Jacks. The standard method of mounting jacks in a switchboard is of interest. Any

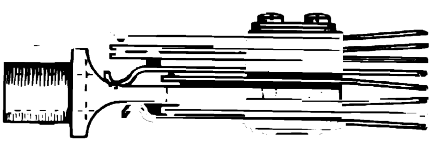


Fig. 292. Eight-point Break Jack

arrangement of fastening jacks must be such that an individual strip of jacks can be withdrawn for maintenance, or additional strips added to meet growth, but under working conditions the whole jack field assembly must be a rigid unit. The vertical stile bars which divide the jack field into panels are drilled and tapped at centres equal to the height of two jack strips. Each strip of jacks has projecting lugs so placed that when the strip is inserted from the rear of the switchboard, the lugs bear against the back of the stile bars when the front of the jack lines up with the face of the switchboard. The jack strips rest one on top of the other and each group of four strips is clamped in position by jack fasteners screwed into the stile bar (Fig. 296). The jack fastener consists of a cheese-headed screw and a thick brass washer from which a sector has been cut. Thus, any strip of the jacks can be released by loosening the screws and rotating the washers to such a position that the lugs of the jack will pass through the cut away sector.

Keys. In telephony, a key is a manually operated switching device in which the contact members are flexed and not pivoted; it is used for opening and/or closing circuits. The keys used in telephone circuits may be broadly divided into two types: *lever keys*, in which the contact members are moved by means of a lever, and *plunger keys*, in which the contact members are moved by a V-shaped plunger. Both types of keys may be either *locking* (remain operated until restored) or *non-locking* (must be held in the operated position). The ringing and speaking key of a cord circuit is possibly one of the more important applications, but keys of various types are nevertheless used for numerous other purposes.

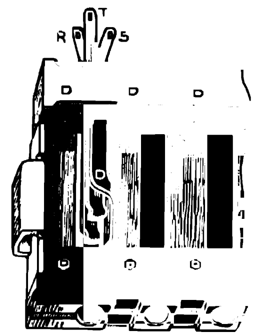


Fig. 293. Portion of a Strip of Ten Branching Jacks
Three-point.

In general, lever type keys are used when a large number of spring combinations are required or when space is not a vital factor, whereas plunger keys have a limited spring capacity but occupy little space and are very suitable for momentary operation. Lever type keys can be arranged with three switching positions (i.e. three-way keys), but plunger keys are limited to the two switching positions.

Lever Keys. A typical lever type key (Key No. 174) is illustrated in Fig. 297. The L-shaped

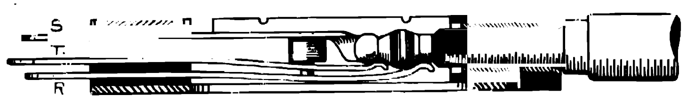


Fig. 294. Plug in Three-point Branching Jack

brass frame carries the contact spring pile and the key lever. The cam of the key lever is of nickel-plated mild steel and possesses a circular recess on its periphery. The key handles are of ebonite for

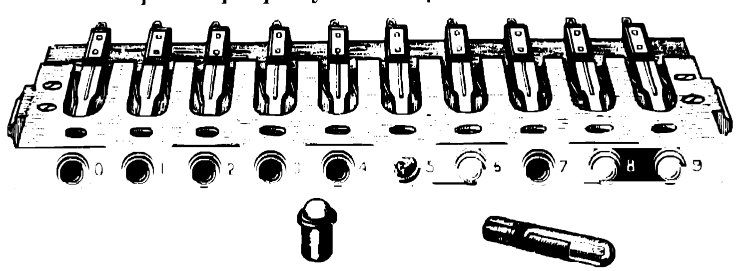


Fig. 295. Strip of Ten Lamp Jacks

black handles, or of galalith or erinoid for coloured handles.

The contact springs are of spring nickel silver, and the connexion tags are tinned to facilitate

soldering whilst the contacts are of gold-silver alloy and are of the point-and-disc type. The insulating spacers and bushings are of ebonite, as also are the rollers carried on the key lever. The long limb of the frame carries a blued steel spring, which exerts pressure on the small nickel-silver plunger, so pressing the steel ball to the edge of the cam. In the normal position, the steel ball enters the recess in the edge of the cam and so locates the key in its central position. Earlier designs of lever key did not possess this feature and trouble was experienced particularly on combined ringing and speaking keys of cord circuits, due to the momentary over-riding when a key was restored to normal.

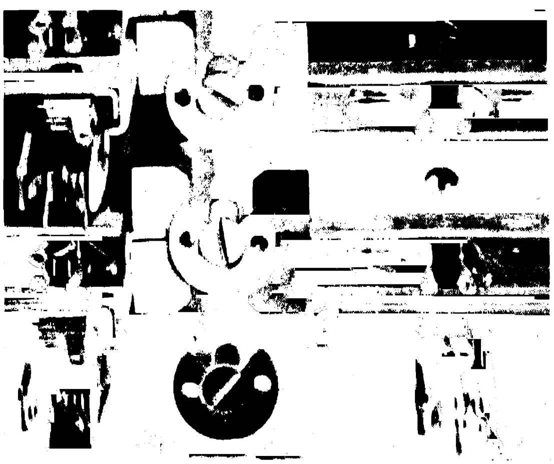


Fig. 296. Use of Jack Fasteners

The main moving spring of a change-over spring set carries a small L-shaped projection which, when the main spring moves, carries the corresponding short spring away from the break spring. This arrangement ensures an adequate contact pressure without critical adjustment of the moving springs.

In the non-locking position, two ebonite buffers are inserted on the under side of the short limb of the frame with the object of limiting the amount of travel of the rollers, thereby preventing locking of the key in this position.

The hole in the cam of the key (Fig. 297) is provided to receive a pin, which is inserted in keys which have only one operated position; the pin prevents movement of the key lever into the unused position.

The actual arrangement of the spring assembly varies considerably, and almost any combination can be accommodated. Where the necessary number of springs cannot be mounted on one key, two or more keys may be used and the key levers clamped together by a long handle. An example of a composite key of this nature is found on the night extension keys on central battery P.M.B.X. switchboards.

Plunger Keys. The construction of a typical Post Office standard plunger key (Key No. 230) is illustrated in Fig. 298. This key is of the non-locking type and makes two contacts when operated. The springs are of nickel-silver and are provided with gold-silver contacts of the point-and-disc type. The key frame is punched from mild steel sheet and is zinc plated. The restoring spring is of hard drawn phosphor-bronze wire. The key top is screwed on to the plunger of the key and possesses a recess for the reception of a number label which is located in position by the two pins projecting from the key plunger.

A locking type of plunger key is illustrated in Fig. 299. Its construction is similar to that of the non-locking key except that the shape of the ebonite plunger is such that, when the moving springs ride over the upper edge of the V-shaped portion, the return of the plunger to normal is prevented. The key is not, of course, provided with a restoring spring, but the springs are restored to normal by lifting up the key handle. Fig. 300 shows a special type of non-locking key strip used for setting up calls to an automatic exchange by depressing in rapid succession the digit keys of the number required. The lever springs of each digit key are fitted with rollers which engage with the wedge of the plunger to give a particularly light and smooth action.

Dial Mountings. The dials used on manual switchboards are fitted into mountings which, in turn, can be plugged into a jack in the keyshelf. It is, by this means, possible to change a faulty dial quickly and thereby avoid putting a position out of service. Fig. 301 shows a typical dial mounting. With this design, the dial is first fitted into a tilting collar which in turn is fixed to the dial mounting. A short flexible cord serves to connect the dial with the four-way plug.

Multi-position Exchanges. The maximum number of subscribers to which one operator can attend depends upon the amount and nature of the traffic involved, but under the best possible conditions this number is limited to some 150 lines and is considerably less when the calling rate is heavy. If, therefore, the number of subscribers increases above the load of one operator, two, three, or more operators' positions must be provided. No difficulty occurs with two positions since either operator can reach the lines terminated on the other position, but if the exchange still further increases in size, it is impossible for any one operator to reach the terminal jacks of all lines. If attempts were made

to connect two subscribers under these conditions, the connecting cords required would be impracticably long.

Transfer Circuits. Possibly the most obvious way of overcoming the difficulty is the provision of circuits interconnecting the various positions so that an operator can extend a calling subscriber to the operator on the position where the required line is terminated. Such circuits (Fig. 302) are known as *transfer circuits* and have been used quite satisfactorily where the amount of traffic is small. Transfer circuits do, nevertheless, necessitate the attention of two operators, and two cords circuits are engaged for the duration of a call. The scheme thus becomes slow and inefficient when the number of subscribers is large and when the volume of traffic is great. In addition, transfer circuits require that each position shall be staffed even during the slack hours of the day. On the other hand, transfer circuits are cheap to provide and although they are nowadays rarely used for the routing of local calls, similar circuits are often employed for passing calls of a special nature from one position to another. Circuits similar in principle to transfer circuits, but intended for inquiries from one operator to another, are also a common feature of a modern exchange and are known as *operator's speaker circuits* or *interposition circuits* to distinguish between transfer circuits which are intended for the routing of normal calls.

Subscriber's Multiple. As an alternative to the provision of transfer circuits, access to all subscribers' lines from any position can be obtained by repeating every subscriber's line jack at intervals along the switchboard, the repetitions being such that any one operator has within reach a jack connected to every subscriber on the exchange. The principle of the *multiple* (as this method of repetition is called) is illustrated in Figs. 303 and 304. Each operator's position in the example shown is divided into two panels, the lower portions of which are reserved for subscribers' calling equipments and answering jacks. The number of subscribers terminated on these two panels is adjusted to provide a load for one operator. Above the answering equipment are the *multiple jacks* which, since they are used only for calls *to* subscribers, are not equipped with signalling lamps or indicators. The multiple jacks are invariably in strips of twenty jacks and are grouped in blocks of five strips to form a complete hundreds group. The

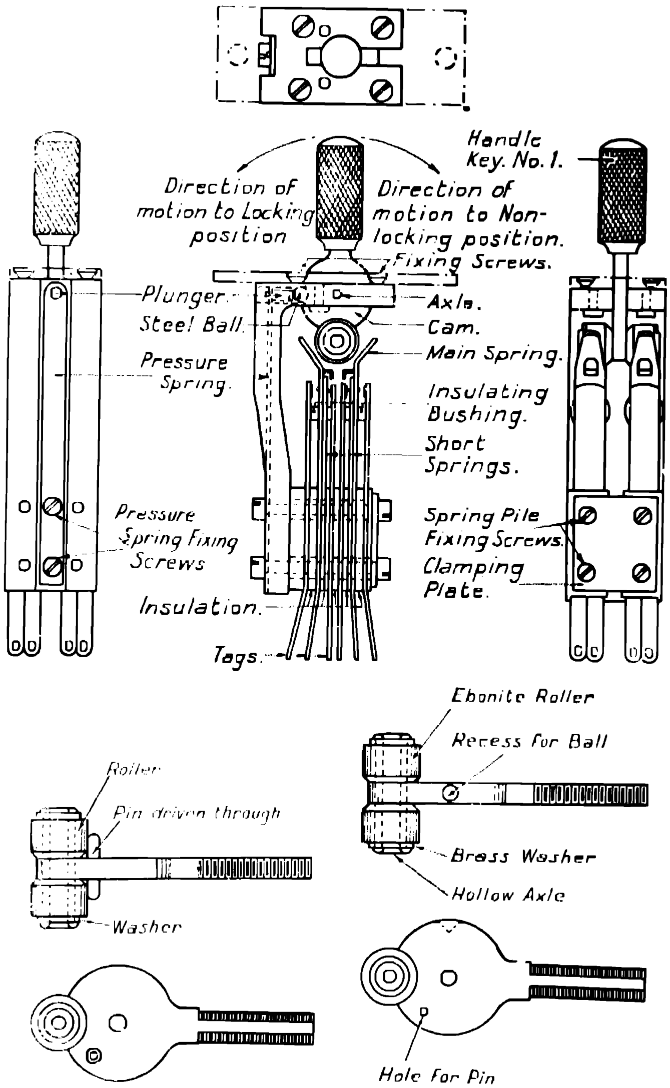


FIG. 297. STANDARD LEVER KEY

groups of one hundred lines each are disposed in numerical order over a predetermined number of panels.

With the switchboard and jacks of fixed design, the arrangement of the multiple is governed by:

(*a*) The ultimate number of lines on the exchange.

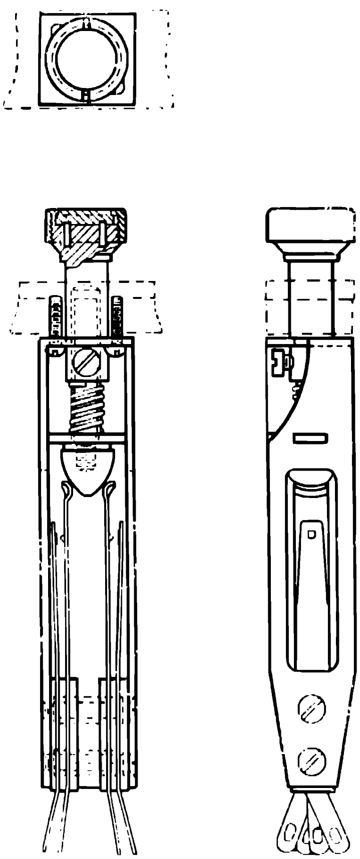


Fig. 298. Non-locking Plunger Key

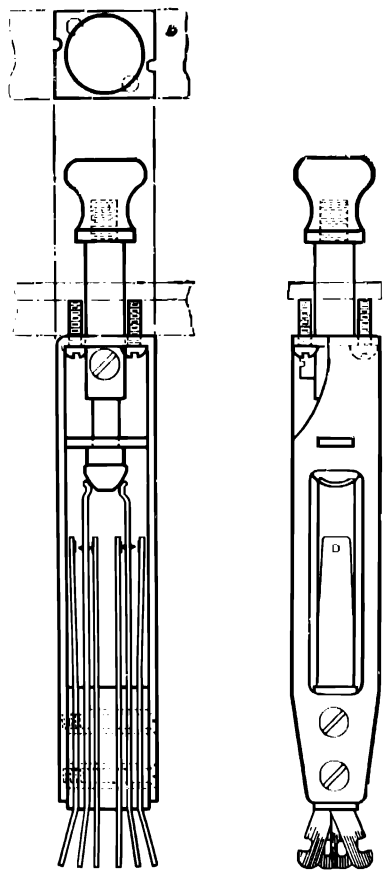


Fig. 299. Locking Plunger Key

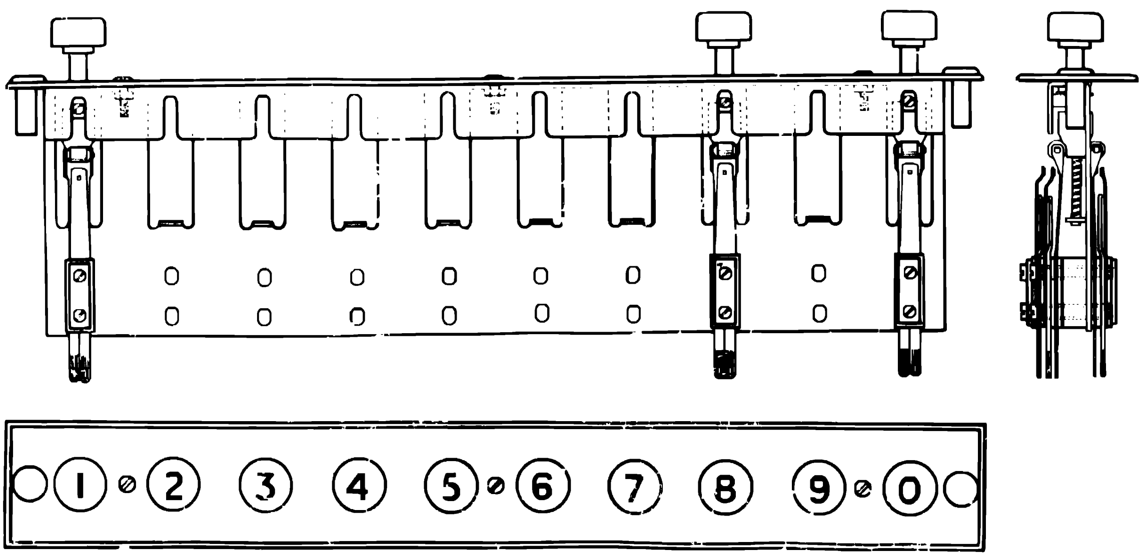
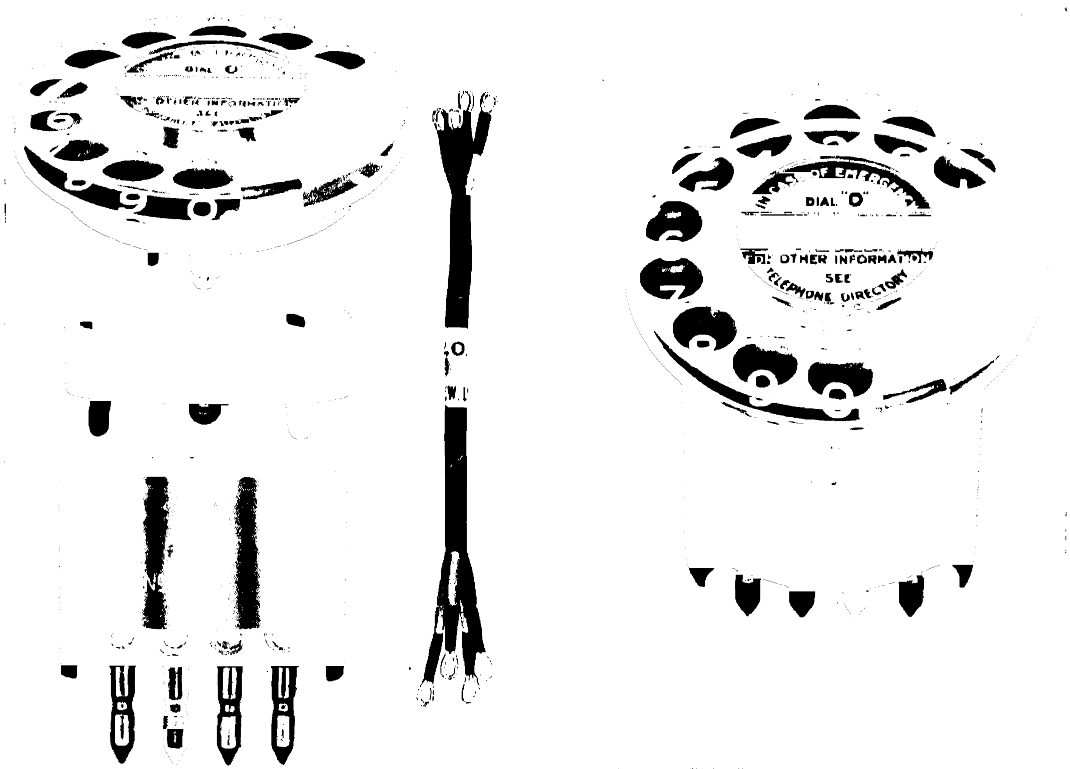


Fig. 300. Keysending Digit Key Strip

(*b*) The maximum reach of an operator.

(*c*) The amount of traffic.

In Fig. 304 provision is made for 1600 lines maximum. A four-panel multiple is adopted which compromise between vertical and horizontal reach is obtained when the switchboard is equipped with the ultimate number of lines. It is of value, however, to aim for some degree of standardization in



(*a*) Unassembled. (*b*) Assembled.

FIG. 301. TYPICAL DIAL MOUNTING FOR SWITCHBOARD

necessitates (at the ultimate date) four layers each of five jack strips. Any operator can, therefore, find any line in the two panels immediately in front of her or in the panel adjacent to each of these. If, with a particular design of switchboard, an operator can reach over a range of, say, six panels, then a six-panel multiple could be adopted with the resulting greater capacity for the same height of multiple. On the other hand, there is no object in requiring an operator to stretch the maximum amount if it is known that a multiple of smaller span will allow ample space for the maximum number of lines on the exchange. Furthermore, the amount of traffic must be taken into consideration in designing the multiple for, whilst it is no hardship for the operator occasionally to stretch the maximum distance, operating is slowed up if she is continually called upon to reach this distance. In general, a multiple is designed so that the best the frequency of multiple repetition in order to facilitate the training and interchange of staff and hence, unless there are strong reasons for departing,

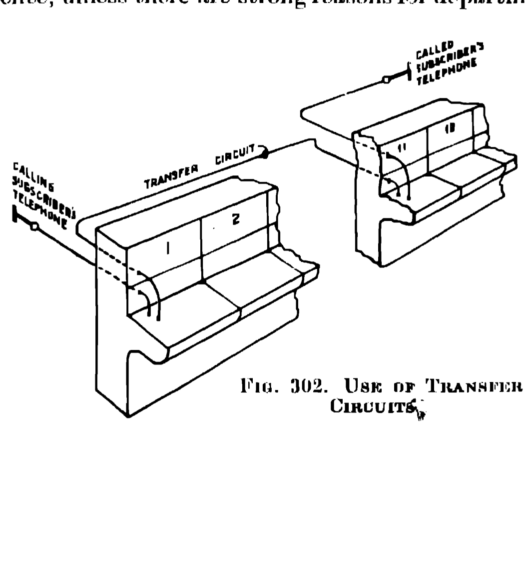


FIG. 302. USE OF TRANSFER CIRCUITS

switchboards of one design are usually provided with a standard multiple arrangement.

It is apparent from Fig. 304 that the operator on position 1 has access to no multiple on her left

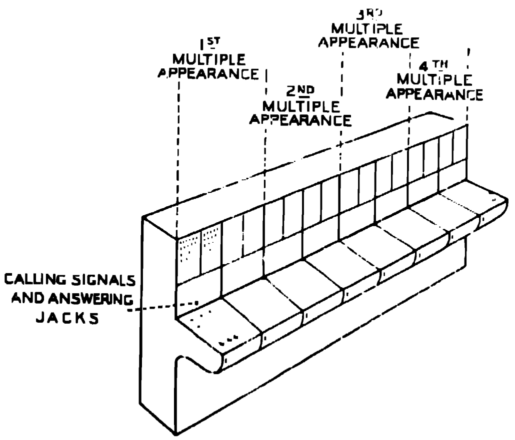


Fig. 303. Principle of the Multiple

hand and it is probable that she cannot reach the multiple jacks in panel 4. This trouble occurs at all end positions and is overcome in practice by the

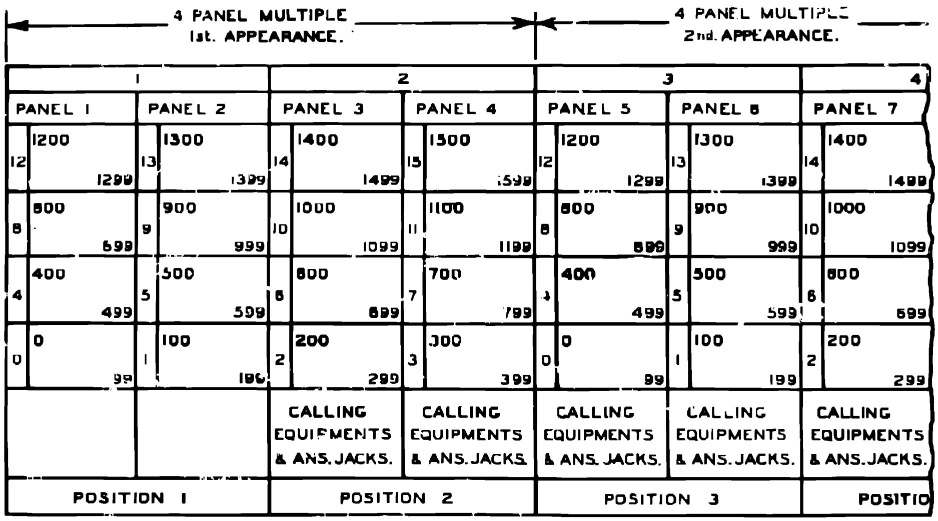


Fig. 304. Four-panel Multiple to Cater for 1600 Lines

provision of a dummy position next to the last staffed position. The dummy position is equipped with multiple jacks only and does not have calling equipment.

Divided Multiple. The capacity of any manual exchange is ultimately determined by the space taken up by the multiple jack field. This capacity can be increased by the adoption of smaller multiple jacks or by extending the span of each appearance to the maximum limit of an operator's reach. There is, however, a limit to the size of jacks beyond which the plugs are too slender and the wiring of the multiple too congested. In the largest type of manual switchboard employed in this country it is possible to accommodate a maximum of 10 000 lines, and when the growth exceeds this number, a second exchange must be opened. In order to avoid the introduction of a second exchange name, an arrangement known as a *divided multiple* has been used in certain large cities abroad. With this scheme, the exchange is virtually divided into two parts—one half of the subscribers' lines being multiplied over half of the positions and the remainder over the second half. Access to the subscribers not appearing in the multiple in front of an operator is obtained over transfer or similar interconnecting circuits between the two sections of the exchange. The use of a divided multiple is really the same as two separate exchanges accommodated in the same building, but has perhaps the slight advantage of a common numbering scheme for the whole area.

Partial Multiple. Many small exchanges have been built up by the addition of several individual positions which are not designed for use as part of a suite and hence have not the space for a standard multiple arrangement. Moreover, the expense of a complete multiple is not warranted and all operating requirements are fulfilled by the addition of small groups of multiple jacks of the lines which are not otherwise accessible to the operator. Such a scheme is known as a *partial multiple* and is

illustrated in Fig. 305. Assuming that each operator has control of 100 lines on her own position and can reach the jacks of lines terminated on adjacent positions only, the operator on position 1 can be given access to all subscribers by the provision on her position of multiple jacks for subscribers 201 to 300. Similarly, the operator on position 3 requires a multiple of subscribers 1 to 100 but there is no necessity to provide a multiple on position 2 since this operator has access to all numbers by reaching over the left and right hand adjacent positions.

Wiring of Multiple. In every system there is associated with each line a calling indicator or relay which must be removed from the line when a connexion is established in order to prevent the transmission loss and out-of-balance conditions which would otherwise occur, and to prevent false operation of the calling equipment. The switching system must therefore be arranged to cut out the calling equipment whenever a plug is inserted in either the answering or one of the multiple jacks of a line.

The conditions can be met by the use of a *series multiple* as shown in Fig. 306. The jacks are designed so that the insertion of the plug disconnects the inner springs from the line and in so doing cuts out the calling equipment from the circuit. Series multiples have in the past been extensively used, particularly in the magneto system, but whilst the scheme is simple, it is subject to high resistance faults at the contacts of the jacks. Moreover, the jacks are more costly and, what is particularly important in a large exchange, they take up considerably more switchboard space than simple jacks without additional springs and contacts. The series multiple has some slight advantage in the case by which a fault in the multiple wiring can be located, but the high fault liability coupled with the space factor has made the series multiple obsolescent for normal exchange work.

A *branching or parallel multiple* as shown in Fig. 307 is invariably used on modern systems. The springs of each multiple jack are paralleled throughout the exchange, but the absence of mechanical means to cut out the calling equipment necessitates the introduction of a *cut-off relay* per line. For obvious reasons, the cut-off relay cannot be operated over the speech conductors and hence a third (or *sleeve*) wire connected to the bushes of all jacks is provided. Three conductor cords and three-way plugs are employed and the circuit is arranged so that battery is applied to the sleeve wire to

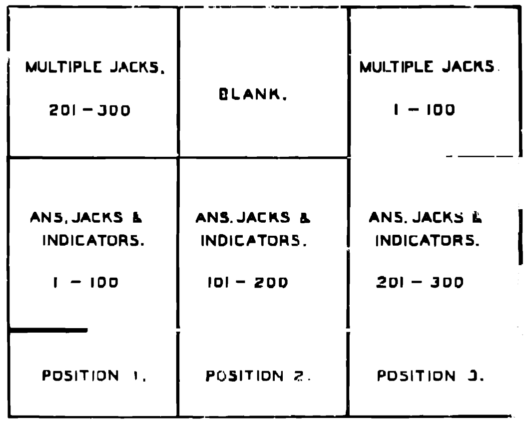


Fig. 305. Partial Multiple

operate the cut-off relay whenever a plug is inserted in a jack.

Engaged Test. In any system involving more than one jack per subscriber's line, it is essential to provide means whereby the operator can ascertain if a wanted line is engaged at any other position on the switchboard. There are, as will be seen later, a variety of ways in which this can be accomplished (e.g. a special lamp associated with each jack which glows when the line is engaged) but space and cost considerations are the determining factors as regards a subscriber's multiple. The universal method for subscribers' multiples is to arrange for a potential on the bush of an engaged line so that an operator hears a click if she taps the tip of a calling plug on the bush of the jack. The principle of the *click test* is given in Fig. 308. If the line is free, there is no potential on the bushes of the jacks and hence no current flows in the secondary of the operator's telephone circuit if the tip of a plug is tapped on the bush. The insertion of a connecting cord into any jack applies the required potential via the sleeve conductor and hence any operator

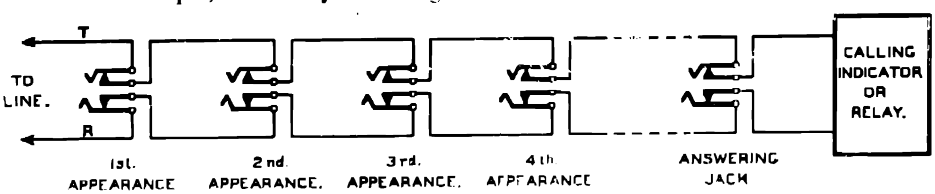


Fig. 306. Principle of the Series Multiple

testing the engaged line receives the click signal due to the surge of current when the tip of the plug encounters the bush potential. As will be seen later, it is usual to combine the operation of the cut-off or sleeve relay with the engaged test requirement so that the energization of the relay also provides the necessary potential drop for the click test.

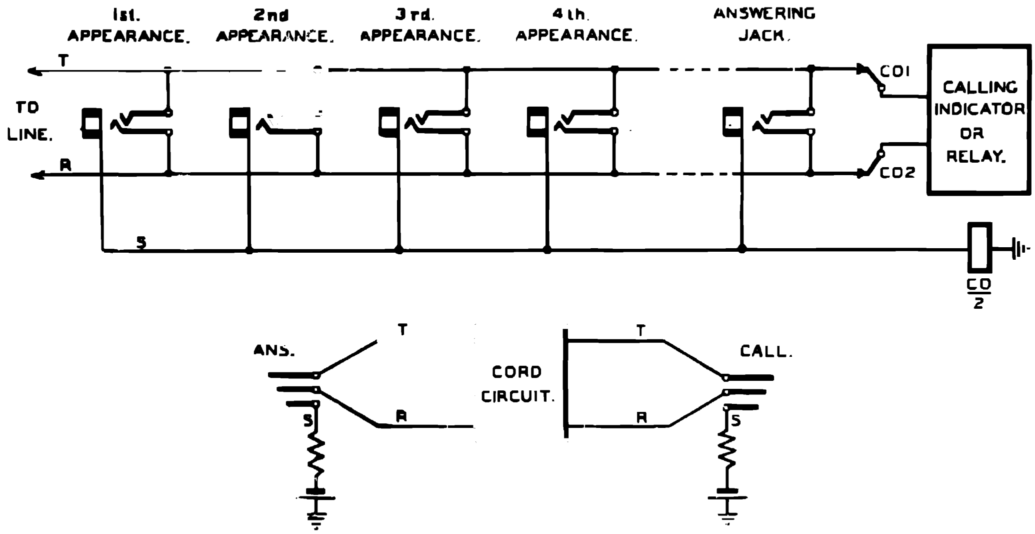


Fig. 307. Principle of the Branching or Parallel Multiple

In exchanges with a series multiple and two-way plugs and cords, the absence of a third conductor prevents the supply of an engaged test potentia from the cord circuit. In multiple exchanges o: this type, auxiliary jack springs are arranged t(apply a battery potential to the bushes of th(multiple jacks when a plug is inserted in any jack. Fig. 309 shows the principle of the scheme. It will be noted that the engaged test potential is not applied to the jack into which the plug is inserted, since the two-way plug connects the bush of this jack to one of the speaking conductors (see Fig. 284).

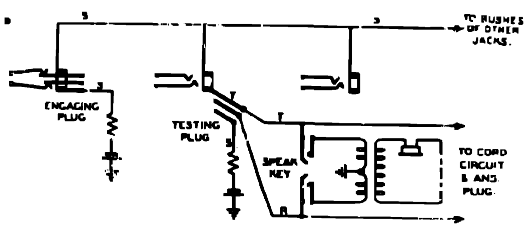


Fig. 308. Principle of the Click Engaged Test

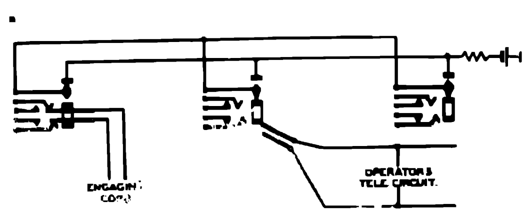


Fig. 309. Application of Engaged Test by Auxiliary Jack Springs

EXERCISES X

1. Explain, with the aid of simple diagrams, the principle of a cordless switchboard. What are the advantages and limitations of the cordless switchboard?

2. Give a diagram of the general arrangements of a cord circuit on a double cord switchboard.

3. What is meant by "positive clearing" and "negative clearing"? Show by means of simple diagrams how a negative clearing signal from a subscriber can be converted to a positive clearing signal at the switchboard.

4. Discuss the principles and relative merits of "sleeve control" and "bridge control" type switchboards.

5. Describe the construction and lay-out of a typical floor pattern switchboard of the double cord type. Sketch the pulley system required when very long cords are to be accommodated.

6. Give a sectional drawing of a modern three-way switchboard plug. Point out how provision is made to prevent the short-circuiting of the tip and ring connexions during insertion of the plug into a jack.

7. Describe the construction of a typical lever type key. Show the difference between locking and non-locking key actions.

8. Explain why it is necessary to "multiple" subscribers' line circuits around the switchboard in a large manual telephone exchange. Describe briefly, with the aid of a simple schematic diagram, the general principles of a multiple arrangement. (*C. & G. Elem. Telecomms. Practice*, 1947.)

9. Give simple diagrams and compare the merits of a series and a parallel type multiple. Why cannot two-conductor switchboard cords be used in conjunction with a parallel multiple?

10. Describe two methods of applying the engaged condition to the jacks of a subscriber's multiple.

CHAPTER XI

PRIVATE MANUAL BRANCH EXCHANGES

SUBSCRIBERS' installations involving a main instrument and several extensions have already been dealt with under "Plan Numbers" in Chapter IX. When the number of extensions exceeds one or two, and particularly when intercommunication between the extensions is required, it is necessary to install at the subscriber's premises a *Private Branch Exchange* (abbreviation P.B.X.) A P.B.X. may be a small local automatic system, or more usually may consist of a manually operated switchboard. To differentiate between the two types, automatic installations are referred to as P.A.B.X.s (*Private Automatic Branch Exchange*) whilst purely manual switchboards are known as P.M.B.X.s (*Private Manual Branch Exchange*).

Broadly speaking, P.M.B.X.s may be classified under three main headings:

(*a*) *Cordless switchboards.* These are small boards designed for installation on a table and where switching is effected by means of keys.

(*b*) *Cord type switchboards.* These are usually floor pattern switchboards employing jacks and cord circuits.

(*c*) *Multiple switchboards.* For very large installations where three or more positions are required.

In addition, there is the House Exchange system which gives direct communication between extensions coupled with exchange line service without the assistance of a P.B.X. operator.

Through Clearing. All modern P.M.B.X.s are arranged to give *through clearing* from the extension to the exchange, i.e. on an exchange call when an extension replaces his receiver a clearing signal is given both to the P.M.B.X. operator and to the public exchange. This ensures that trunk and junction time is not wasted due to delay in clearing by the P.M.B.X. operator. Apart from this, however, through clearing has become essential for the proper timing of trunk calls since the introduction of automatic timing devices under the control of the subscriber's switch-hook. The main disadvantage of through clearing at P.M.B.X.s is that an extension cannot attract the attention of his local operator without the risk (particularly in automatic areas) of releasing the connexion. To meet this requirement, operator *recall facilities* can be provided on some types of installation.

Power Supply. The smaller P.M.B.X.s are designed to operate with a power supply at a minimum pressure of 12 V. Normally power is supplied for these smaller boards by means of primary cells or a power lead from the exchange. Both these sources possess an appreciable impedance at speech frequencies and hence it is usual to provide a large capacitance condenser ($8\ \mu F$) across the P.M.B.X. busbars to prevent overhearing. The larger P.M.B.X.s are usually served by a 24 V secondary cell installation. (See Ch. XX.)

Transmission Bridge. On most P.M.B.X.s there is very little difference in line resistance between the various extensions. Advantage is taken of this to provide a cheap form of transmission bridge with a single two-winding impedance coil to serve both extensions (see Fig. 95). The transmission bridge is, moreover, required only on extension-to-extension calls, and a high degree of balance and transmission efficiency is therefore not necessary.

Night Switching. All P.M.B.X.s provide facilities for connecting selected extensions to the exchange lines during the night period when the switchboard is not staffed. Under normal day conditions, a clearing signal is given at the P.M.B.X. when the receiver of an extension so extended is on the rest. Switching relays are also operated to cut out the local transmission bridge on exchange calls. It is undesirable (especially from a power wastage point of view) that these relays and supervisory indicators should remain operated throughout the night period. Night service switching keys are therefore provided to disconnect the local transmission bridge and supervisory indicators under night service conditions.

Switchboard Designation. Non-multiple P.M.B.X. switchboards are designated in the Post Office by a fractional index which describes the quantity of equipment and the capacity of the board. Thus the designation:

$$\frac{2+4}{6} = \frac{\text{equipment for two exchange lines plus four extensions}}{\text{capacity for six lines (exchange + extension)}}$$

Similarly:

$$\frac{10+60}{180} = \frac{\text{equipment for ten exchange lines plus sixty extensions}}{\text{capacity for 180 lines (exchange plus extension)}}$$

Cordless Switchboards. There are four standard cordless type switchboards;

$$\frac{1+3}{4}, \frac{2+4}{6}, \frac{3+7}{12} \text{ and } \frac{3+9}{12}.$$

They are all of the same general appearance and differ only in the number of lines and connecting links. Fig. 310 illustrates the $\frac{2+4}{6}$ type switchboard. The exchange lines are terminated on drop indicators whilst eyeball indicators are provided for the extensions. Two rows of three-way keys complete the face equipment of the switchboard. The keys are wired so that when two keys in the same horizontal row are thrown in the same direction the appropriate lines are connected together through a link circuit. Operating is facilitated by adding coloured strips to indicate the direction in which the keys must be thrown to associate with a given connecting link. The bottom position of the lower row of keys is reserved for applying hold conditions on the exchange lines and for ringing the extensions. The vertical row of keys on the extreme left is for night switching, whilst the operator's telephone is associated with the similar row on the right.

An incoming call drops the indicator of the exchange line and the operator answers by selecting a disengaged connecting link and throwing the appropriate exchange line key and her telephone key in the direction of the selected link circuit. After ascertaining the number required, the operator calls the required extension by depressing the Ring Key and turning the handle of the generator. When the extension answers, a key of that extension is moved to the chosen connecting link, and after verifying that the call is correctly established the operator restores her telephone key. The procedure on outgoing and extension to extension calls is very similar, but great care is necessary on outgoing calls to ensure that the connexion is not released. The operator must be certain that the extension loop is holding the call before she dissociates her telephone. If this is not possible, the exchange line Hold Key must be operated until the extension receiver is lifted. At the termination of a call the extension indicator reoperates as a clearing signal until such time as the keys are restored.

The circuit arrangements of the connecting keys and link circuits are shown in Fig. 311. The $80 + 80\ \Omega$ retard coils in each link circuit provide the simple transmission bridge. The coils are so connected that the operation of any exchange line key cuts off the transmission bridge from the link. Similarly the operation of any extension key breaks the circuit of the relevant calling indicator. A supervisory relay (*AA*, *AB*, etc.) is inserted in the *B*-line of each link. The contact of this relay (*AA*1, *AB*1, etc.) provides a circuit for the reoperation of the extension indicator at the end of a conversation until the switching key is restored. Alarm contacts on all indicators energize a buzzer to provide an audible alarm. When the night switching key is thrown, the supervisory circuit is broken

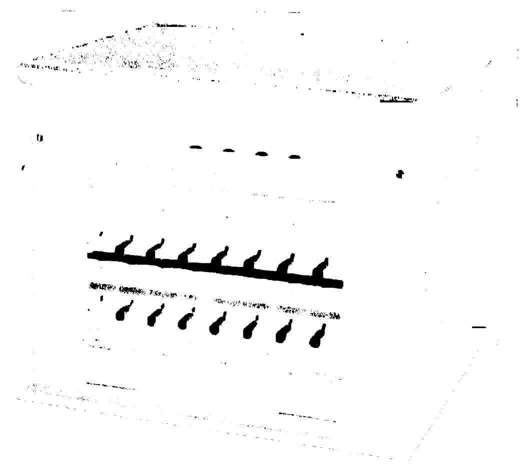


Fig. 310. Typical Cordless P.M.B.X. Switchboard (Switchboard No. $\frac{2+4}{6}$)

at *NS*2, *NS*3, etc., whilst the alarm circuit of the exchange line indicators is disconnected at *NS*1. (The transmission bridge is cut out at the exchange line key.)

The circuit conditions when an exchange to extension call is set up are summarized in Fig. 312, in which the key contacts have been omitted for clarity. Fig. 313 shows in a similar manner the conditions on an extension to extension call. It will be noted that relay *AA* is in the common battery feed to both extensions, and hence the clearing signal energizes both extension indicators only when the *last* party replaces his receiver.

Cordless Switchboard—L.B. Areas. The cordless switchboard described above is suitable for use in C.B. or automatic areas. A switchboard of similar appearance is also available for use in C.B.S.1, C.B.S.2 or magneto areas or on long lines in C.B. or auto areas. Fig. 314 shows the elements of one connecting link. The key contacts have been omitted, but the detailed connexions can be readily deduced by a comparison with Fig. 311. No transmission bridge is necessary with this switchboard, but a supervisory relay *R* is provided in each connecting link and is isolated from the exchange

line by the 2μF condensers. Contact $R2$ provides a reoperate circuit for the extension indicators via the switching key to give a positive clearing signal. Contact $R1$ places the 250 Ω hold coil across the condensers so that an extension can call the exchange direct under N.S. conditions. Contact $NS2$ breaks the clearing signal circuit to the extension indicator as before. It is interesting to compare

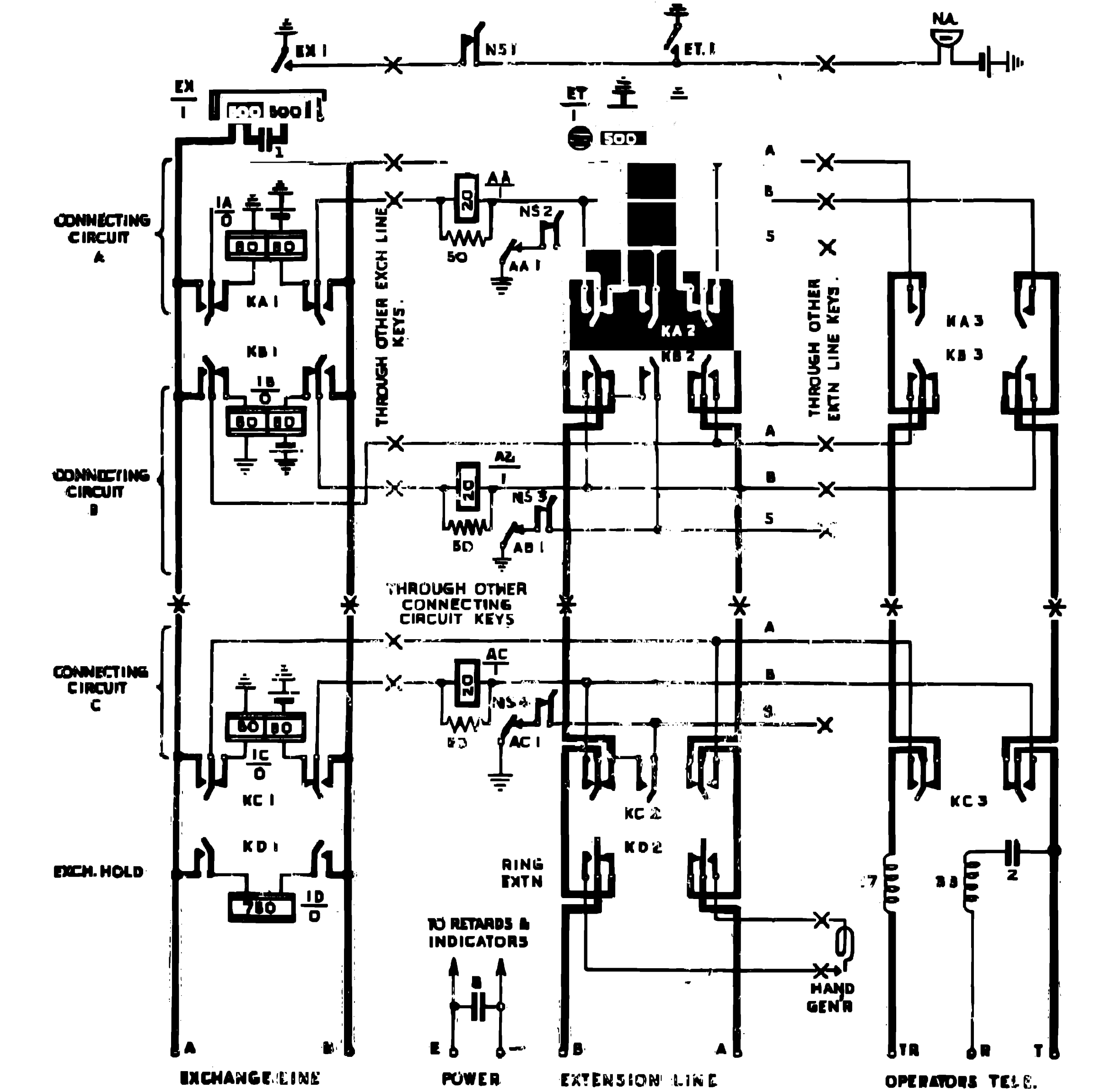


Fig. 311. Circuit Arrangements of Cordless Switchboard

exchange line whilst the extension receiver is off, thereby providing a holding loop to the exchange. In C.B.S.1 areas, the back contact of $R1$ is wired to earth to give the normal clearing signal at the termination of a call (earth on A-line). The night switching key disconnects R and bridges the the circuit arrangements after switching (Figs. 315 and 316) with those of the C.B. type switchboard (Figs. 312 and 313). In magneto areas, a generator must be associated with the operator's instrument and must also be fitted at each night service extension.

Magneto Switchboards. Although magneto working is rapidly becoming obsolete, mention should perhaps be made at this stage of two types of magneto switchboard which have proved very useful during the war period for the switching of circuits where generator signalling is employed.

The single cord type of magneto P.M.B.X. is illustrated in Fig. 317, whilst Fig. 318 gives the fundamental circuits. The principle of single cord working has already been discussed in Chapter X. A plug and jack are associated with each line and

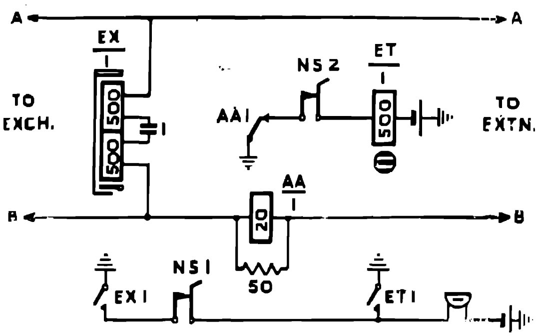


FIG. 312. THROUGH CONDITIONS ON AN EXCHANGE-TO-EXTENSION CALL

with the operator's telephone. When two lines are connected together one of the drop indicators is left across the line to receive the ring off signal. This indicator is condensered to maintain switch-hook control of the exchange timing device. The generator of the operator's instrument is so arranged that when calling a line via the plug, the

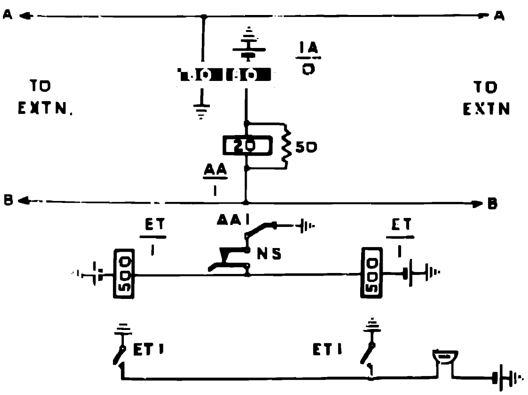


FIG. 313. THROUGH CONDITIONS ON AN EXTENSION-TO-EXTENSION CALL

ringing current does not pass to a waiting party connected to the operator's jack.

The double cord wall type switchboard (Fig. 319) is of more conventional lay-out with break jacks and a ring-and speak key in the cord circuit. The

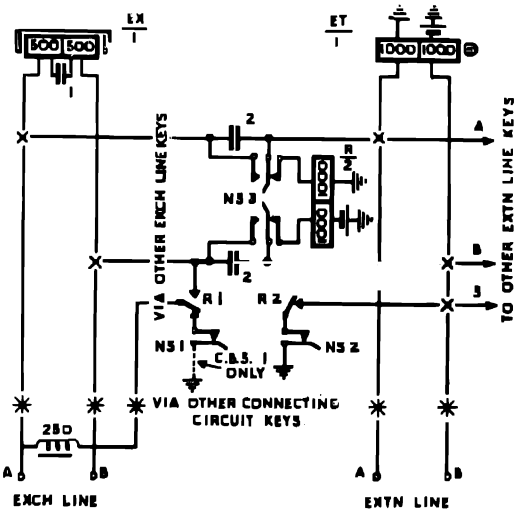


FIG. 314. ELEMENTS OF CORDLESS SWITCHBOARD FOR USE IN L.B. AREAS

cord circuit ring off indicators are permanently bridged across the line and hence are of the high impedance type.

25-Line P.M.B.X. The smallest floor pattern

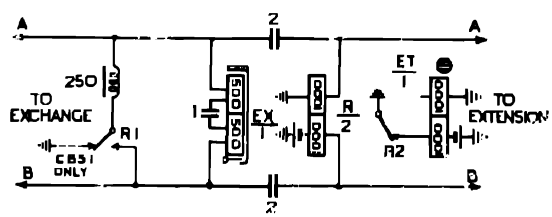


FIG. 315. THROUGH CONDITIONS, EXCHANGE-TO-EXTENSION CALL

cord type switchboard for use in C.B., automatic, and C.B.S. areas is illustrated in Fig. 320. It has a capacity for five exchange lines and twenty extensions, and provision is made for a maximum of eight cord circuits. It is usually installed with its

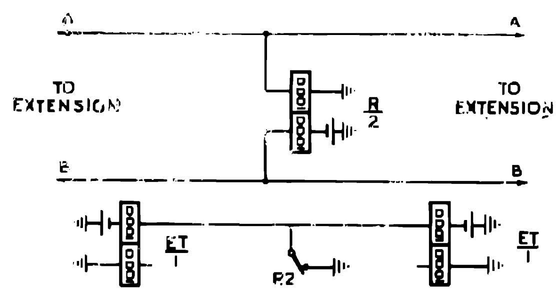


FIG. 316. THROUGH CONDITIONS, EXTENSION-TO-EXTENSION CALL

back adjacent to a wall, and access to the interior is obtained by swinging open the hinged front.

The complete circuit arrangements are given in Fig. 321. A simple undivided transmission bridge (*FR/O*) is provided in the cord circuit and is disconnected on exchange calls at *S*1 and *S*2. The bush of an extension line is left disconnected, whilst a full earth is connected to the bush of each exchange line jack. If, therefore, a plug is inserted in an exchange line jack, relay *S* operates to remove the transmission bridge. The supervisory relays (*A*) are, contrary to the usual practice, associated with the extension line circuits. At the termination of a call, relay *A* releases due to the break in the extension loop, and at *A*1 reoperates the extension indicator to give a positive clearing signal until the plug is removed from the jack. The operator's telephone circuit is provided with an anti-sidetone coil and is of normal design. In addition to the cord circuit speak-and-ring key, a ring-back key is also provided. This latter key is also operated when dialling on the calling cord to dissociate the answering plug from the dialling circuit. The night service switching key disconnects the extension indicator, the transmission bridge and the alarm bell. It also removes the earth from the bushes of the exchange line jacks to prevent the unnecessary operation of relay *S*.

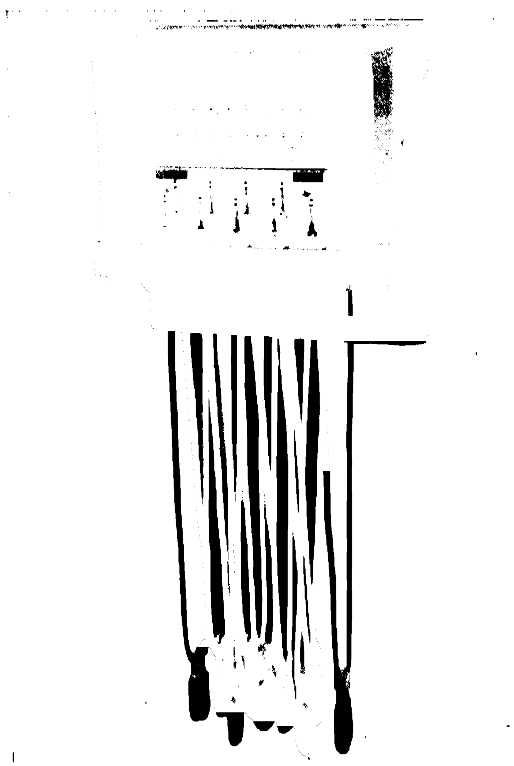


Fig. 317. Single Cord Magneto Switchboard

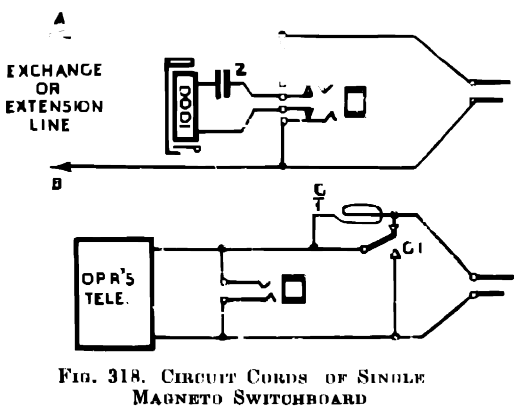


Fig. 318. Circuit Cords of Single Magneto Switchboard

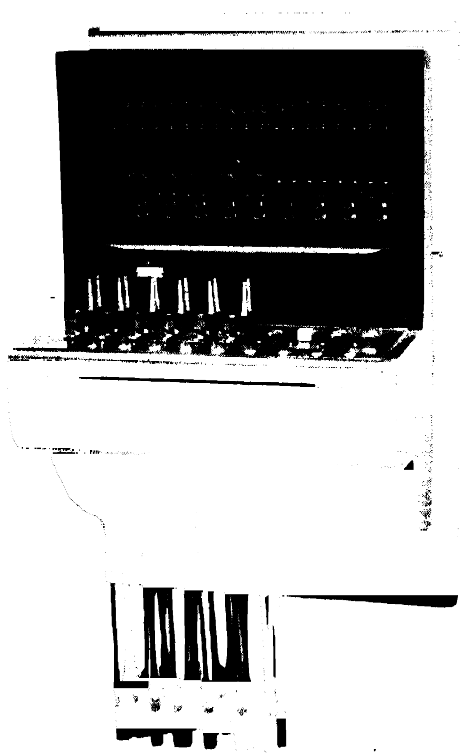


Fig. 319. Wall Pattern Double Cord Magneto Switchboard

65- and 180-Line P.M.B.X.s. A larger type of floor pattern non-multiple P.M.B.X. is available when the requirements exceed the capacity of the 25-line switchboard. Two models of the large

board have been standardized. The first provides for an ultimate capacity of fifteen exchange lines and fifty extensions $\left(\frac{10+30}{65} \text{ and } \frac{10+50}{65}\right)$ whilst the second has a maximum capacity of twenty exchange lines and 160 extensions $\left(\frac{10+60}{180}\right)$. The two types are very similar in appearance (Fig. 322) apart from the fact that the jack field of the larger board is arranged in two panels. There is also some slight difference in the positions of the exchange line jacks, and the 180-line switchboard has a capacity for eighteen cord circuits as compared with fifteen on the smaller model. Access to the interior is obtained through the removable rear panel and hence it is essential to leave a space behind the switchboard for maintenance. Although the switchboard is not intended to form part of a suite, the design is such that two positions can readily be installed in a continuous line if required.

The main difference between this switchboard and the 25-line P.M.B.X. is the provision of supervisory indicators in the cord circuits. The indicators are of the "sixpenny" type and separate indicators are provided for the answering and calling cords. These supervisory signals are "negative" in operation, i.e. the indicator discs are visible whilst a call is in progress and disappear at the termination of a call. This is the reverse of the "positive" clearing signals provided on the cordless and 25-line switchboards. The extension and exchange indicators are of the doll's eye and drop type respectively and the usual speak, ring, and ring-back/dial keys are provided.

Fig. 323 shows the circuit arrangements. As before, exchange line discrimination is effected by earthing the bushes of all exchange line jacks. On extension to extension calls relay S is not operated due to the absence of an earth on the sleeve conductor and the $80 + 80\,\Omega$ transmission retard coil (*FR*) is connected to the speaking conductors. The supervisory indicators A and B operate to the calling and called extension loops and provide to the operator a visual indication of the progress of a call.

When a connexion is set up through an exchange line, relay S operates to the earth on the bush of the exchange line jack. ***S1*** and ***S2*** remove the transmission bridge from the tip and ring wires and substitute a holding loop (*FR* and *HR* in series) under the control of $C1$. Whilst the extension receiver is off the rest, relays A and B operate in series from the current in the loop to the exchange. ***A1*** and ***B1*** complete a circuit for relay C which locks via the speak key contacts and ***C2*** to the earth in the sleeve circuit. ***C1*** in turn removes the holding loop from the cord circuit. This arrangement ensures that a call is not accidentally released whilst it is being extended to an extension, but at the same time it allows through clearing at the termination of a call.

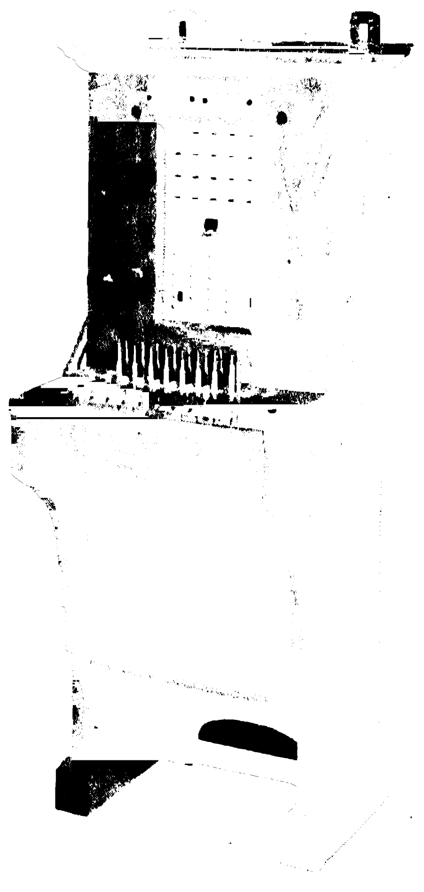


FIG. 320. 25-LINE P.M.B.X. SWITCHBOARD
(Switchboard $\frac{5+20}{25}$)

The night service key when operated removes the transmission bridge and breaks the operate circuit for relays S and C. The operator's telephone circuit is of modern design which minimizes side-tone and prevents acoustic shocks to the operator (see Chapter V). It will be noted that in order to economize in power consumption the operator's transmitter circuit is completed only when a speak key is thrown. The $200\,\Omega$ resistor and $1\,\mu F$ condenser act as a spark quench circuit for the speak key contacts.

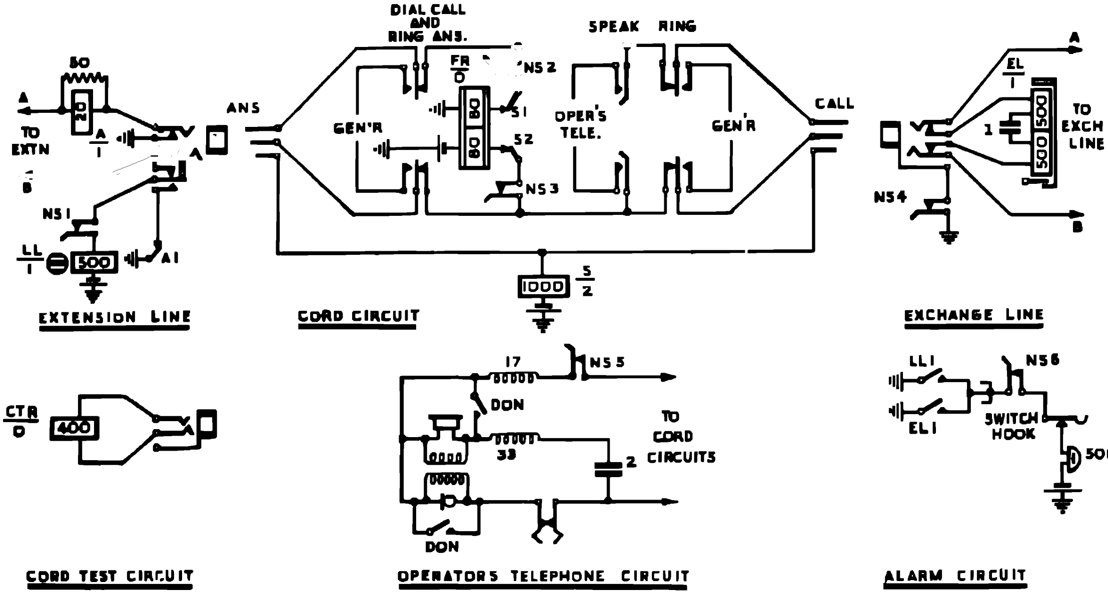
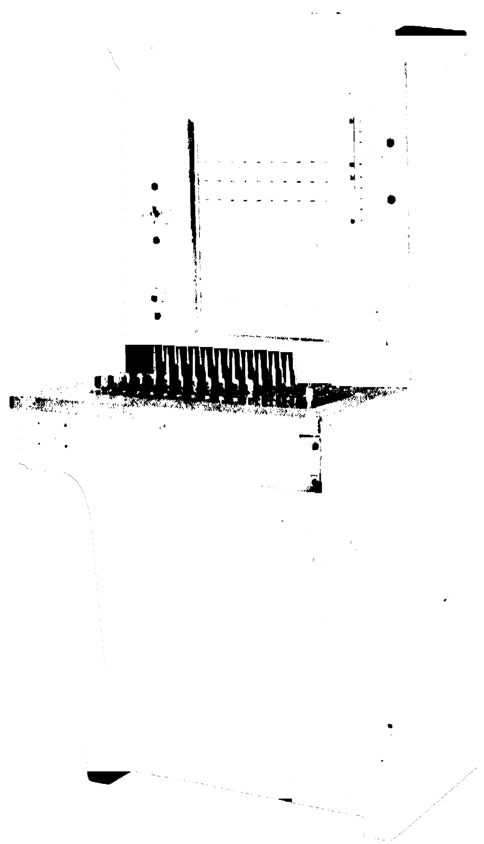


FIG. 321. CIRCUITS OF 25-LINE SWITCHBOARD



No. 9 Type P.M.B.X. The Post Office No. 9 type switchboard is a floor pattern, double-cord board of the multiple type and until recently was the standard P.M.B.X. when more than two positions were required. It has now been superseded for new work by the P.M.B.X. No. 1A described later.

The switchboard is made up of single position sections each of two panels. Each section has a capacity for twenty exchange lines, 200 extensions, and seventeen cord circuits. There are no separate answering jacks, but all lines are multipled on a four-pane repetition basis throughout the suite. The multiple space available limits the total capacity of the switchboard to 160 exchange lines and 800 extensions.

Figs. 324 and 325 illustrate the extension and exchange line circuits. A series multiple with break jacks is employed and when a plug is inserted into any jack, auxiliary contacts place a 200 Ω engaged test battery on the bushes of all other jacks in the multiple. On earlier installations, self-restoring drop indicators (Fig. 163) were provided on the exchange lines. The indicator disc was operated by the incoming ringing current, and when a plug was placed in a line jack, auxiliary springs completed a circuit for a restoring coil on the indicator to the battery on the sleeve of the plug. This arrangement has now been superseded by the circuit shown in Fig. 325 in which an eyeball

FIG. 322 65-LINE P.M.B.X. SWITCHBOARD
(Switchboard $\frac{10 + 30}{65}$)

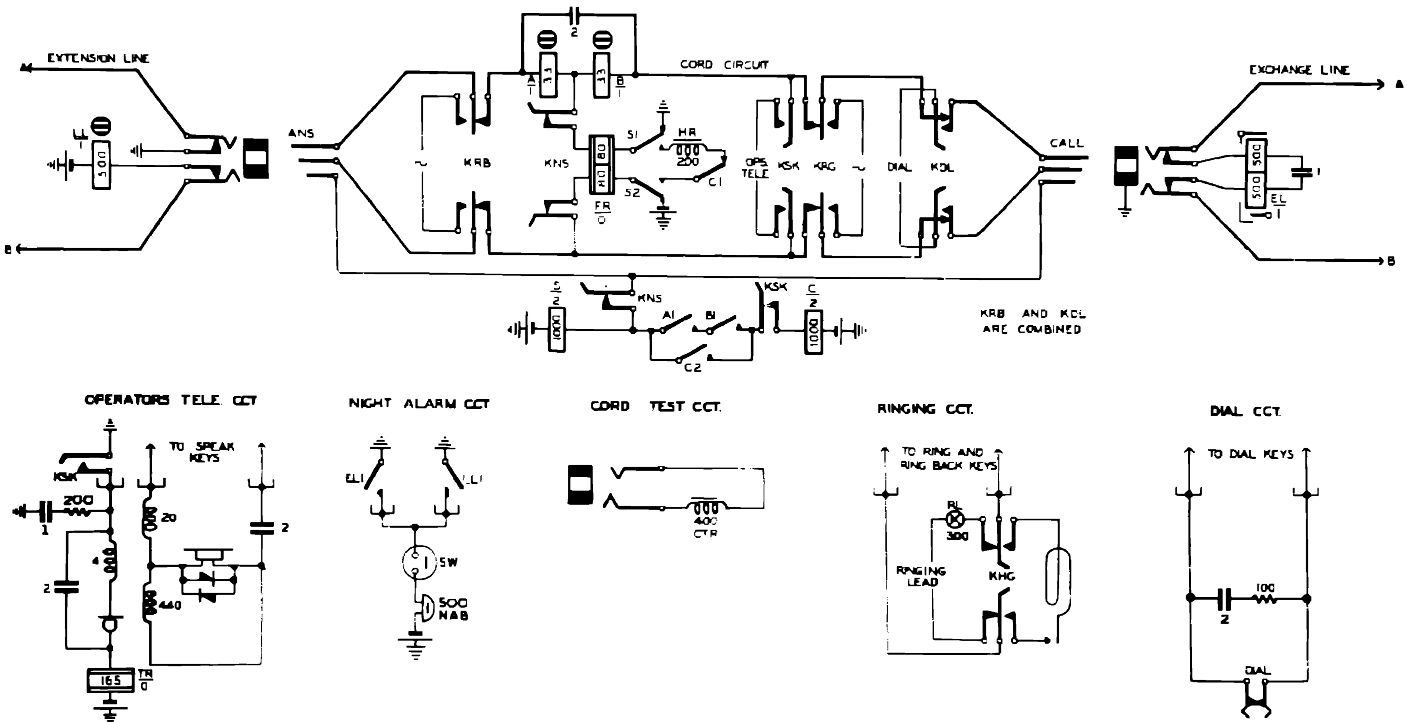


Fig. 323. Circuit Details of Large Type Floor Pattern P.M.B.X.

(Switchboards $\frac{10-30}{65}$, $\frac{10-50}{65}$, and $\frac{10-60}{180}$)

indicator in conjunction with a metal rectifier is used to receive the incoming ring. The eyeball indicator locks in the operated position on its second coil. When a plug is placed in the line jack, relay *S* operates to the battery on the sleeve of the plug and at *S1* releases the calling indicator.

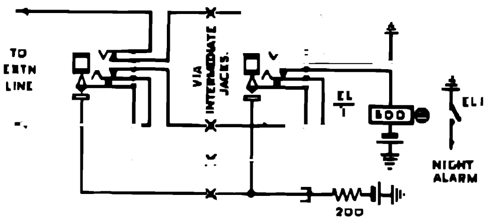


FIG. 324. EXTENSION LINE CIRCUIT
(No. 9 type P.M.B.X.)

The cord circuit of the No. 9 P.M.B.X. is substantially the same as that of the 65- and 180-line switchboards.

A secondary cell installation providing a minimum bus bar voltage of 16 is required, the consumption of a typical four-position exchange being in the order of 16–20 Ah/day.

P.M.B.X. No. 1A. The P.M.B.X. No. 1A is the new standard switchboard for subscribers' installations where more than two positions are required. The new item supersedes the C.B. No. 9 type switchboards already described. The basic unit of a P.M.B.X. No. 1A is a two-panel single-position section of modern design and is 4 ft. 6 in. high by 2 ft. 2 in. wide (Fig. 326). The sections are designed to bolt together to form a continuous switchboard and the suite is completed by 1 ft. 0 in. wide cable turning sections fitted at each end. The keyshelf is equipped with twelve cord circuits with wiring for an ultimate of sixteen cord circuits per position. Each pair of cords is fitted with a speak-and-ring key and a ring-back/dial key. Separate supervisory lamps are provided for the answering and calling cords.

Each panel of the jack field has a capacity for forty exchange lines arranged in strips of ten jacks, and for 200 extension lines arranged in strips of twenty jacks. Each position has therefore a maximum capacity of eighty exchange lines and 400 extensions. All lines are multipled on a four-panel repetition basis throughout the suite, and hence the maximum capacity of the P.M.B.X. No. 1A is 160 exchange lines and 800 extensions. Inter-switchboard lines and private wires are fitted in the exchange line multiple.

All circuits are lamp calling and an unusual feature is the absence of separate answering lamps and jacks. Normally ebonized blanks are inserted between the multiple jack strips, but at one of the multiple appearances this blank is replaced by a strip of calling lamps above the multiple jacks. The switchboard does not provide multiple answering facilities or ancillary working for the extension lines, there being only one calling lamp per circuit. The distribution of calling signals is normally determined at the design stage by traffic requirements, and it is usual to arrange for the calling lamps of each group of twenty extensions to appear on one specified panel. Flexibility may, however, be obtained when required, by providing a second lamp strip at another multiple appearance so that individual calling lamps may be transferred from one answering position to another in order to equalize the operators' loads.

A series multiple is employed for the extension circuits in order to avoid the provision of a cut-off relay per line. A special low consumption lamp (17 V 45 mA) has also been introduced to eliminate the need for a line relay on internal extensions of low line resistance. The lamp is connected in series with the battery feed to line and lights from the current in the line when the wires are looped by the lifting of the extension receiver. Amber-coloured lamp caps are used to produce a light of uniform colour irrespective of the line resistance. Provision is made for line relays to be fitted when the extension circuits exceed 200 Ω loop resistance.

The exchange line and private wire multiple is of the parallel type and facilities are provided for a

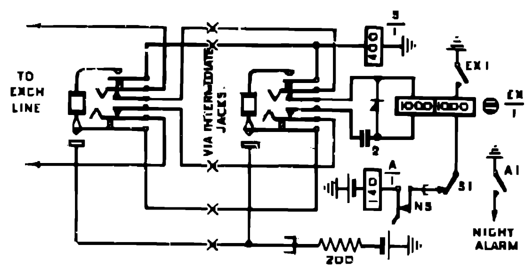


FIG. 325. EXCHANGE LINE CIRCUIT
(No. 9 type P.M.B.X.)

"primary" and a "secondary" calling lamp. Usually, the primary appearances are concentrated on the centre positions of the suite with the secondary lamps spread evenly over the remaining equipped panels.

The cord circuit and miscellaneous position apparatus is fitted at the rear of the section in the usual way, but separate racks are required for the line termination apparatus. The apparatus racks are 2 ft. 9 in. wide and 7 ft. 0 in. high and have been reduced to two standard designs. The first and more common unit contains the necessary

connexion strips for the termination of the cables from the M.D.F. and multiple together with the long extension line relays, the fuse panels, and the relay sets required for exchange lines, etc. The second is a supplementary rack to accommodate relay sets on installations where there is an abnormal number of exchange lines, private wires, etc. All the usual forms of signalling on private wires are catered for by two standard relay sets which are provided with strapping facilities to meet the required signalling conditions.

Facilities of P.M.B.X. No. 1A. The P.M.B.X. provides the following facilities:

1. Individual positive supervision is given on extension-to-extension calls.

2. Separate battery feed is given to the calling and called lines on extension-to-extension (or P.W.) calls.

3. Ring and dial facilities are provided on the calling cord, and the ring-back facility is provided on the answering cord.

4. The standard "click" engaged test is provided.

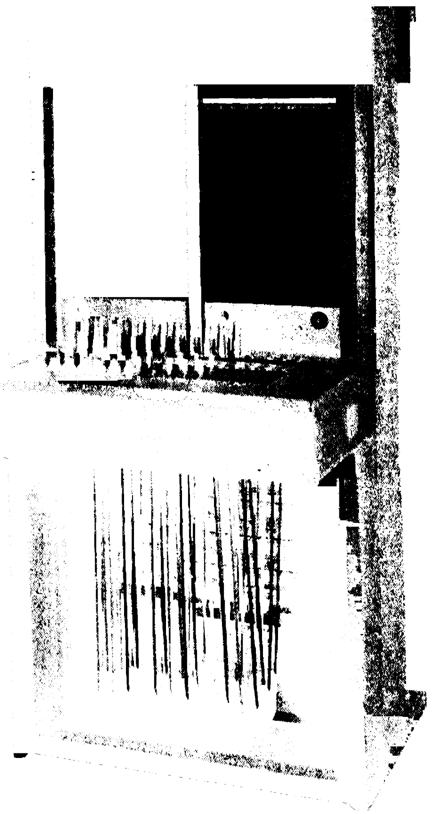
5. Through clearing from extension to public exchange is standard and both supervisory lamps on the P.M.B.X. light when the extension clears.

6. Direct dialling from extension to public exchange is possible.

7. Press button operator recall can be provided when required.

8. When an incoming exchange call is received before the operator clears the previous connexion, the supervisory lamps will flash and the incoming ring is prevented from calling the extension.

9. Night service conditions can be set up without the use of separate cords or night service keys.



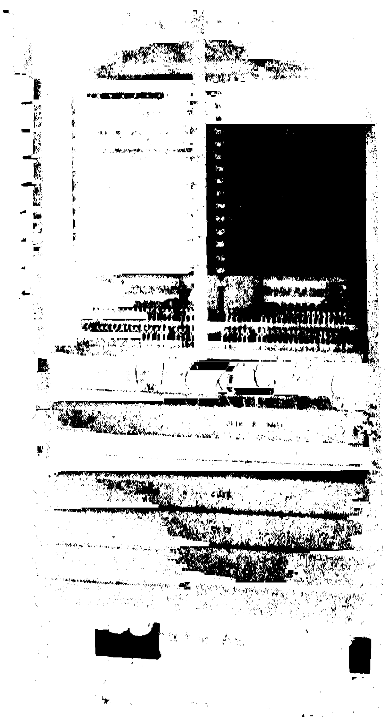


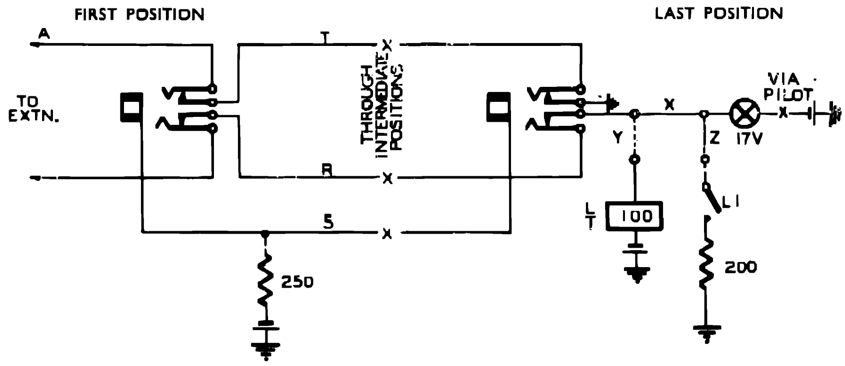
FIG. 326. P.M.B.X. No. 1A

Multiple jacks not fitted.

Front view. Rear view.

10. A pilot lamp per position and a common alarm bell for the suite are provided.

Extension-to-extension Calls. The extension and exchange line circuits of P.M.B.X. No. 1A are given in Figs. 327 and 328, whilst Fig. 329 shows



NOTE. STRAP X REMOVED & STRAPS Y & Z INSERTED WHEN LOOP RES OF EXTN. LINE EXCEEDS 200 Ω

FIG. 327. EXTENSION LINE CIRCUIT, P.M.B.X. 1A

the cord and miscellaneous position circuits. In the extension line circuit, an earth is applied via the contact springs of the multiple jacks to the *A*-line and battery via the 17 V calling lamp (or *L* relay on long lines) is placed on the *B*-wire. The lifting of the receiver at the extension lights the calling lamp in the usual way via the loop. The operator at the calling position places the answering plug of a free cord circuit in the line jack of the calling extension and throws the speak key. The speak key contacts place the operator's telephone across the cord circuit and energize relay *SK* and its relief relay *SKR*. Further springs of the speak key complete the operator's transmitter circuit. The operation of contact ***SK*3** causes relay *AS* to operate from the earth at ***SK*7** to the 250 Ω battery in the sleeve circuit of the extension line. At the same time, the current in this circuit produces a potential drop across the 250 Ω resistor to give the necessary conditions for the click engaged test. The original operate circuit of *SK* is broken at ***AS*5**, but an alternative holding circuit is now provided through ***SK*4**, ***AS*4**, and *LC*2; the momentary break during the movement of ***AS*5** and ***AS*4** being covered by the slow release feature of ***SK***. ***AS*3** and ***AS*6** complete the transmission bridge to the calling extension. Relay *L* now operates to the extension loop.

After ascertaining the number required, the operator taps the tip of the calling plug on the bush of the appropriate multiple jack. A circuit is completed from battery, the 2 μF condenser and 20 000 Ω resistor in parallel, speak key springs, *LC*3, *CS*6, one coil of relay *LC*, ***SKR*5**, ring and dial key to the bush of the jack. If the required line is engaged, the potential drop in the sleeve resistance gives rise to a surge of current to charge the 2 μF condenser. This surge in passing through *LC* produces a momentary potential across the speaking pair which in turn gives rise to a current pulse and click in the operator's receiver. The effect is further enhanced by an induced e.m.f. in the second winding of *LC* during the surge of current in the first winding. It should be noted that a full negative battery on the bush is the free condition and either an earth or reduced negative potential indicates that the circuit is engaged. This arrangement is the converse of the usual arrangement in public manual exchanges.

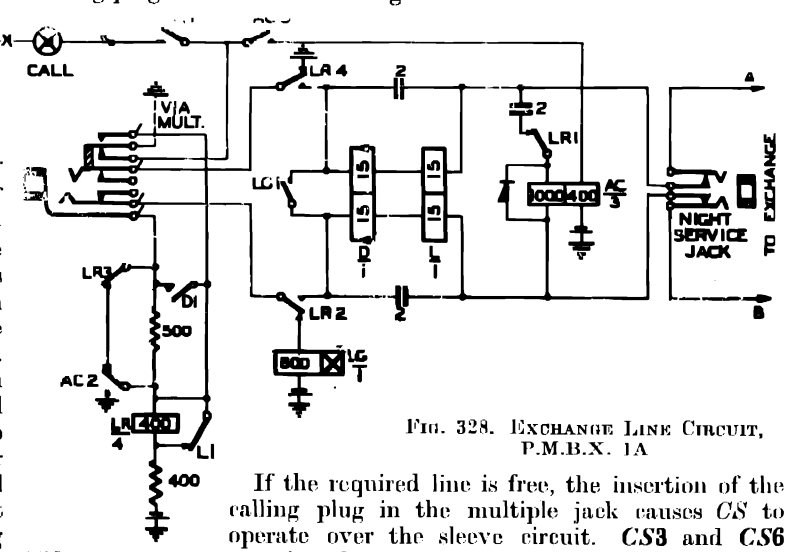


FIG. 328. EXCHANGE LINE CIRCUIT, P.M.B.X. 1A

If the required line is free, the insertion of the calling plug in the multiple jack causes *CS* to operate over the sleeve circuit. ***CS*3** and ***CS*6** complete the second half of the transmission bridge, whilst ***CS*2** lights the calling cord supervisory lamp via ***SK*6** and *LC*1. Ringing of the called extension is effected in the usual way and, when the extension

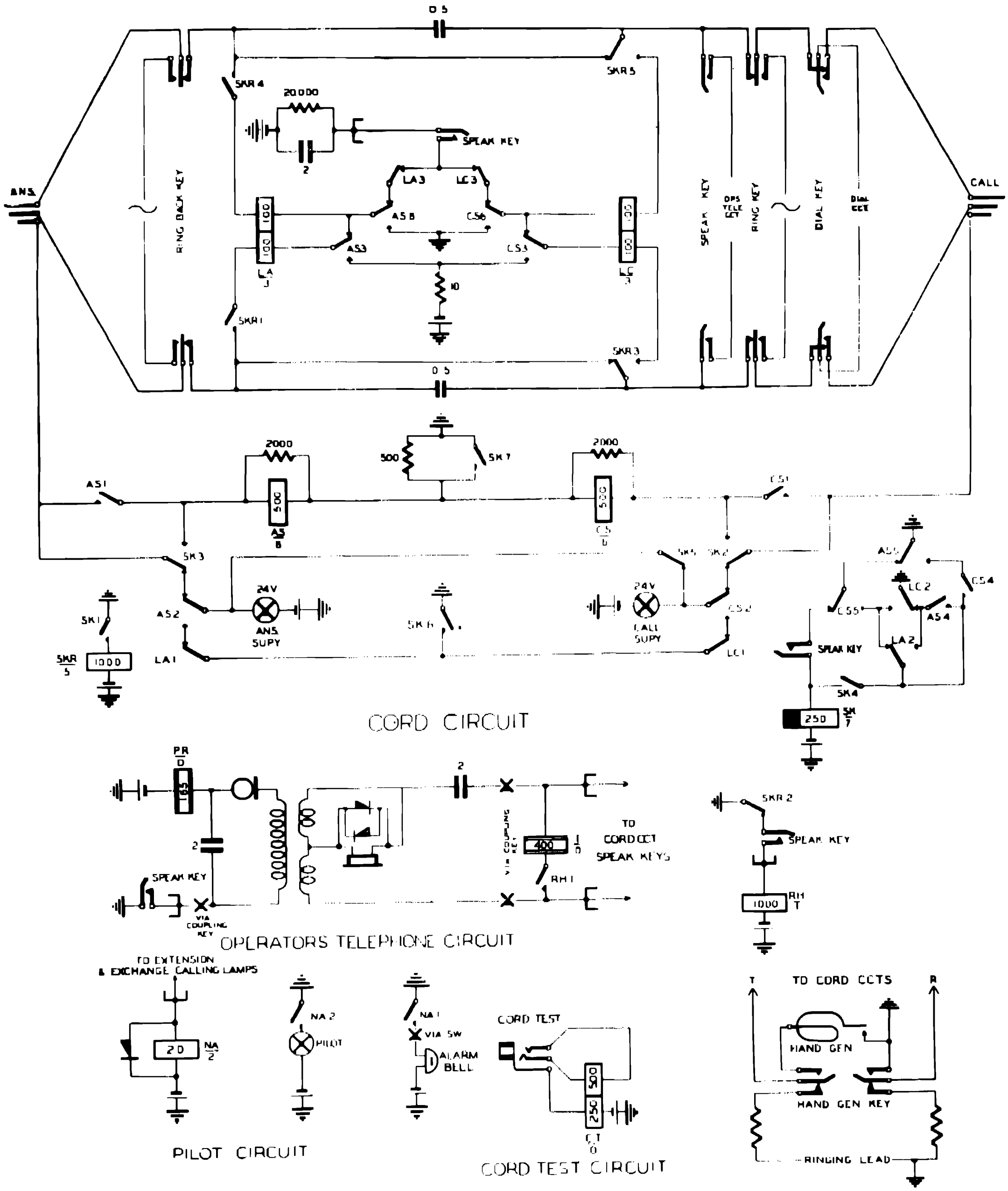


Fig. 329. Cord and Miscellaneous Circuits, P.M.B.X. 1A

answers, relay LC operates over the loop. **$LC1$** extinguishes the supervisory lamp and **$LC2$** removes the holding earth from the SK relay. The latter is, however, now held under the control of relays AS (at **$AS5$**) and CS (at **$CS4$**).

At any time during the progress of the call, either extension can obtain the attention of the operator by flashing the switch-hook. This breaks the loop and allows relay LA or LC to release,

The placing of an ANS plug into the jack of th calling line operates the auxiliary jack springs an thereby releases relay AC and extinguishes th calling lamp. The make contacts of the auxiliar springs provide a full earth on the bush of the jac to replace the function of $AC2$. Both cord circui supervisory lamps glow to the earth on the bush When the speak key is thrown, the supervisor lamps are disconnected at **$SK3$** (Fig. 329). Th

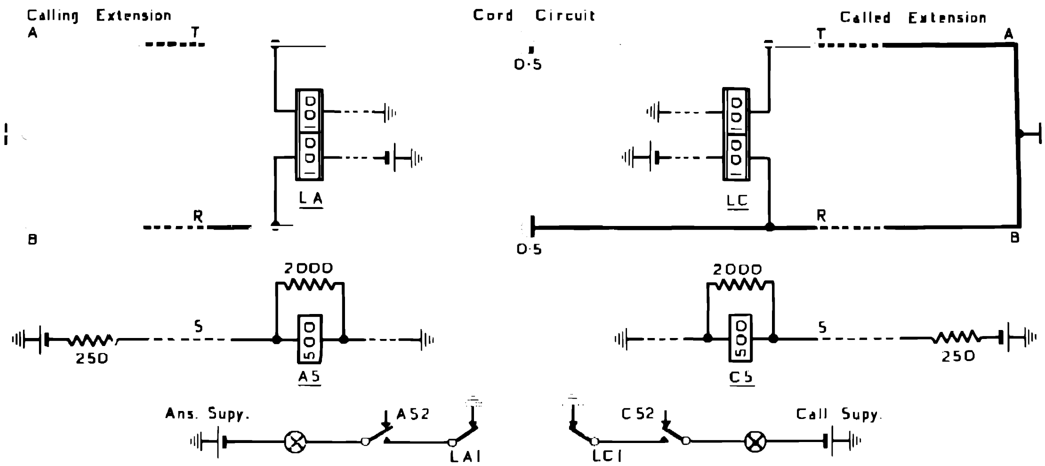


FIG. 330. CONVERSATIONAL CONDITIONS ON EXTENSION-TO-EXTENSION CALLS (P.M.B.X. 1A.)

thereby completing a circuit for the appropriate supervisory lamp at $LA1$ or $LC1$ (Fig. 330). At the termination of the call the continuous glowing of the supervisory lamps gives a positive indication to the operator that the connexion can be taken down. The removal of the plugs releases AS and CS and they in turn allow relays SK and SKR to release.

Incoming Exchange Call. The exchange lines are terminated on eight-point jacks with auxiliary contact springs (Fig. 328). These auxiliary springs are wired in series throughout the multiple, but the line springs are wired in parallel and not in series as the extension multiple. Relay AC operates to the ringing current received from the exchange. **$AC1$** lights the calling lamp from the earth through the auxiliary jack springs, whilst **$AC3$** provides a locking circuit for AC from the same earth. **$AC2$** applies earth via 500 Ω to the bushes of all jacks to provide the necessary engaged test as described above. It should be observed that an engaged condition is placed on the exchange line multiple from the moment the calling signal is received, whereas the multiple jacks of an extension line are not busied until the calling condition is answered by the insertion of a plug.

same contact applies relay AS to the sleeve circuit, but the relay does not operate due to the absence of battery in the circuit. **$SKR1$** and **$SKR4$** apply both coils of relay LA in series to the tip and ring of the ANS plug. This 200 Ω loop operates relay LG in the exchange line termination via contacts $LR2$ and $LR4$ (Fig. 328). **$LG1$** completes a d.c. loop across the exchange A- and B-lines through the both coils of relays L and D (i.e. a 60 Ω loop). The loop trips the ringing (if automatic) and provides the necessary conditions for metering and supervision at the exchange. Relay D is differentially wound and does not operate with the loop current. Relay L operates and at **$L1$** removes the short circuit from relay LR. **$LR1$** removes relay AC from the speaking pair to cut out the transmission loss, whilst **$LR3$** inserts 500 Ω in the earth connexion to the sleeve circuit. **$LR2$** and **$LR4$** switch through the exchange line to the cord circuit and break the circuit for LG. The loop across the exchange line is now provided by relay LA in the cord circuit, the slug on LG ensuring that the loop is not momentarily broken during this change over. LA in the cord circuit and L in the line termination are now operated in series.

After ascertaining the extension required, the operator tests and (if free) seizes the line. Relay CS

perates to the battery in the extension sleeve ircuit and at **CS3** and **CS6** provides a temporary ransmission bridge for the extension. The hold ircuit of *SK* is broken at **CS5**, but an alternative ircuit via **SK4**, **LA2**, and *LC*2 was provided on he operation of *LA*. **CS2** lights the calling cord upervisory lamp. When the extension replies, *LC* operates to the loop and at **LC1** extinguishes the supervisory lamp. **LC2** allows *SK* to release.

public exchange operator, the exchange line immediately tests as a free line. Special arrangements are provided to ensure that if a "follow on" call is received before the P.B.X. operator has cleared the previous call, the calling signal will be properly received and the extension to which the exchange line is connected will not be troubled unnecessarily. At the termination of an exchange call, the short-circuiting of *LR* by the release of

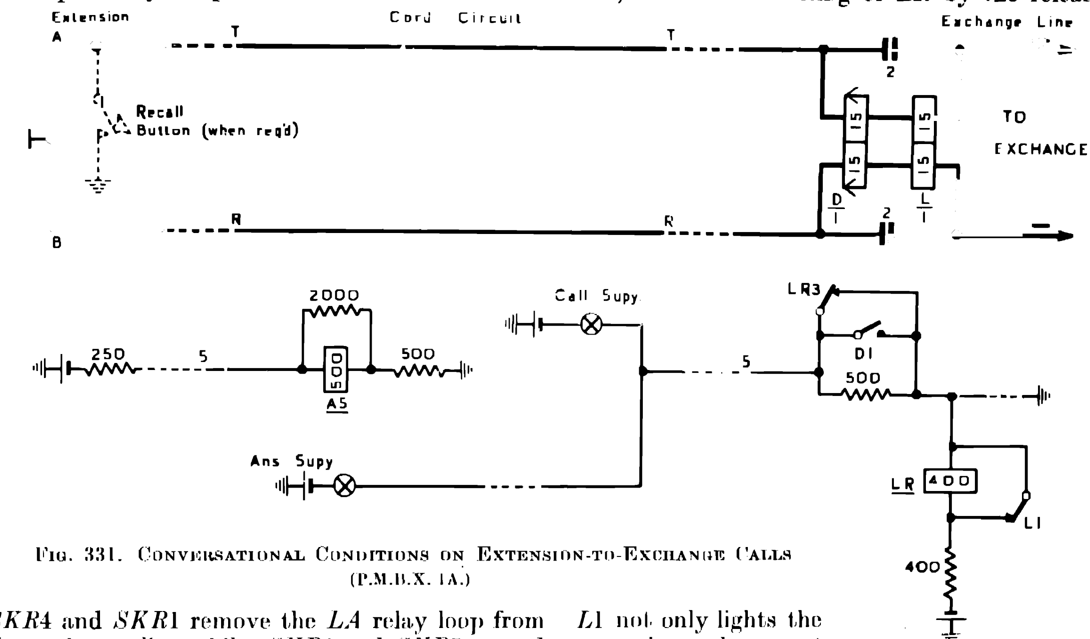


FIG. 331. CONVERSATIONAL CONDITIONS ON EXTENSION-TO-EXCHANGE CALLS (P.M.B.X. 1A.)

*SKR*4 and *SKR*1 remove the *LA* relay loop from the exchange line whilst *SKR*3 and *SKR*5 extend the extension loop to the exchange line by short-circuiting the cord circuit condensers. The speaking conductors of the cord circuit are now straight through without any bridging or series apparatus. On the release of *SK*7, relay *CS* holds to the 500 Ω earth and the reduced current in the sleeve circuit maintains the engaged condition on the extension multiple. Both supervisory lamps are now controlled by the conditions on the sleeve of the exchange line jack. (See Fig. 331 for outgoing exchange calls.)

The operator may monitor the call at any time by throwing the speak key. Under these conditions, *CS*5 avoids interruption of the circuit by preventing *SK* and *SKR* from operating when the speak key is thrown. When the call is terminated, relay *L* releases and at *L*1 short-circuits *LR*. *LR*3 in turn short-circuits the 500 Ω resistance in the sleeve circuit and the increased current allows both supervisory lamps to glow.

Follow-on Call. When a call incoming to the P.B.X. is released by the calling subscriber or

*L*1 not only lights the supervisory lamps at *LR*3 but also disconnects the exchange line from the switchboard at *LR*2 and *LR*4. The incoming ringing current of a follow-on call is received by relay *AC*, but the locking circuit of this relay is broken at the auxiliary jack springs. **AC2** therefore pulses in synchronism with the received ringing current, and by removing the short circuit from the 500 Ω resistance causes both supervisory lamps to flash in unison with the received ring.

Outgoing Exchange Calls. The circuit operation during an originated exchange call is very similar to the incoming call already considered. The operator places the calling plug of a convenient cord circuit into the multiple jack of a free exchange line and throws the speak key. **SKR3** and **SKR5** apply the *LC* relay loop to the line which operates *LG*. **LG1** repeats the loop to the exchange and the current in this loop operates *L*. **L1** in turn removes the short circuit from *LR* which at **LR2** and **LR4** extends the exchange line to the cord circuit. Relay *LG* now releases after a lag period and removes the temporary loop at *LG*1. This sequence

of operations ensures that, in automatic areas, a false initial impulse is not given to the exchange due to the momentary short-circuiting of the *T* and *R* jack springs during the insertion of the plug.

The required number is passed orally in a manual area, or the number is set up by means of the dial key and dial in automatic areas. At the end of the call, both supervisory lamps glow and the exchange line is released when the calling extension receiver is replaced.

Operator Recall. In an automatic area it is not possible for an extension to recall the P.B.X. operator on an outgoing exchange call by flashing the switch-hook. When the facility is required, separate recall press buttons are fitted at selected extensions (Fig. 331). The operation of this button applies an earth to the *A*-wire of the extension. Normally, the current in the two windings of relay *D* (exchange line termination) are equal and their magnetic effects are arranged to neutralize. When the recall button is pressed one winding is in effect short-circuited by the earth. Relay *D* operates and at ***D*1** cuts out the 500 Ω resistance, thereby lighting the supervisory lamp associated with the exchange line.

Night Service. On those exchange lines where night service facilities are required, an extra night service jack is provided. These jacks are located at the top of the jack field and are so wired that the insertion of a plug cuts off the normal exchange line terminal equipment (Fig. 328). Night service conditions are set up by inserting the answering and calling plugs of any convenient cord circuit into the required extension jack and the exchange line night service jack. All cord circuit keys are left normal. Under these conditions, the *T* and *R* conductors of the cord circuit are straight through and the supervisory relays are out of circuit. There is also no operating circuit for the sleeve relays or supervisory lamps. The extension can therefore receive and originate calls in exactly the same way as a direct exchange line. If the speak key is accidentally operated whilst a night service connexion is set up, relay *SK* locks up, the sleeve relay associated with the extension side of the cord circuit is operated, and the supervisory lamp glows. Under these conditions the connexion must be taken down and re-established.

Private Wires. Private wires terminating on a P.B.X. may employ diverse signalling methods depending upon the characteristics of the line itself and on the type of the distant equipment. The normal combinations of calling and clearing signals on a bothway circuit call for well over a dozen different arrangements of terminal apparatus. In the P.M.B.X. No. 1A the maximum degree of standardization consistent with reasonable econon can be attained by two types of relay set. The fir (Fig. 332) is designed primarily for d.c. signalli only, whilst the second (Fig. 333) is a univers relay set which can be arranged to work with an of the usual combinations of d.c. and generat signalling.

D.C. Signalling P.W. Relay Set. The relay se normally responds to a calling signal of earth on the *A*-line, although it can be used for loop calling by the insertion of strap *Y* (Fig. 332). The calling earth operates relay *LL*, which through ***LL*1** lights the calling lamp. The insertion of an answering plug into the line jack and the throwing of the speak key allows relay *S* (line termination) and relay *AS* (cord circuit) to operate in series. ***S*1** operates the relief relay *SR* which locks via its own contact (***SR*3**) to the earth on the auxiliary jack springs. ***S*2** and ***S*3** switch through the speaking conductors, whilst ***SR*2** extinguishes the calling lamp and provides an operate circuit for *LR*. ***SR*1** returns a supervisory earth on the *B*-wire to the distant end. ***SR*4** in conjunction with strap *X* provides a hold circuit for *S* to the auxiliary jack spring earth. Strap *X* is inserted if the facility of extending the private wire to an exchange line is required. As described previously, relays *SK* and *SKR* release on the restoration of the speak key after connexion is made to an exchange line jack. When strap *X* is omitted, the release of *SK* removes the full earth from the sleeve circuit and so releases *S*. *S*2 and *S*3 disconnect the speaking conductors and thereby prevent access to the exchange line.

After the operation of *SR*, relay *LR* is held under the control of ***LL*1**. ***LL*2** applies a loop through *I* to operate the cord circuit supervisory relay (*LA* or *LC*) or to hold an exchange connexion. When the calling earth on the *A*-line is removed at the termination of a call, *LL* and *LR* release, and the disconnexion of the *I* loop gives the required clearing signal.

On outgoing calls, *S* and *SR* operate when the speak key is thrown and ***SR*1** applies the calling earth to line. When the distant end answers the supervisory signal operates *LL* and ***LL*1** operates *LR* to close the supervisory loop at ***LR*2**. It should be noted that the *A*- and *B*-lines must be reversed at one end of the circuit to give correct calling and supervisory conditions. Usually a circuit which employs d.c. signalling in one direction is also capable of d.c. signalling in the other direction. Circumstances do, however, occasionally arise when the type of terminal equipment enables d.c. signalling in one direction only. By connecting strap *Z*, the circuit can be arranged for generator

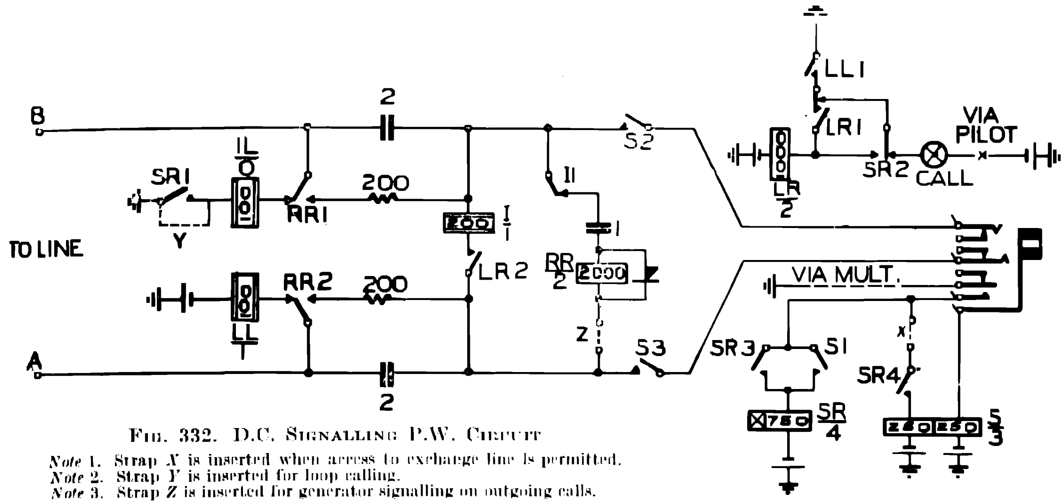
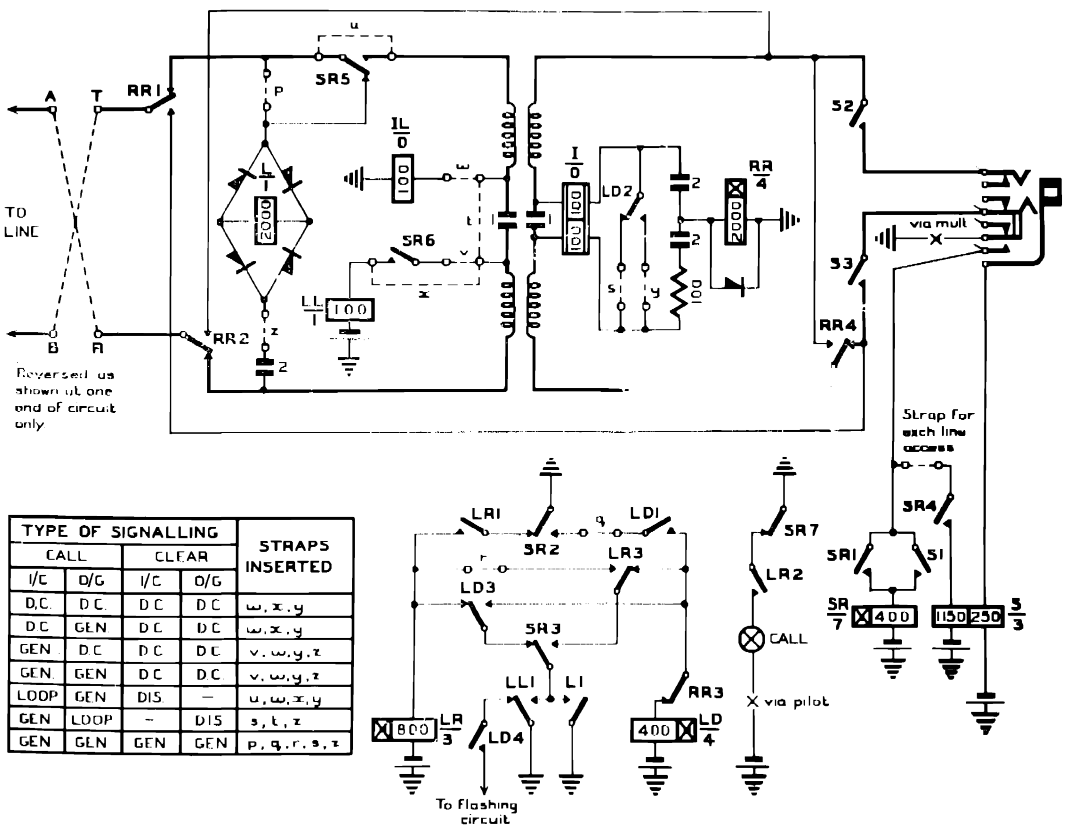


Fig. 332. D.C. Signalling P.W. Circuit

Note 1. Strap X is inserted when access to exchange line is permitted.
Note 2. Strap Y is inserted for loop calling.
Note 3. Strap Z is inserted for generator signalling on outgoing calls.



TYPE OF SIGNALLING				STRAPS INSERTED
CALL		CLEAR		
I/C	O/G	I/C	O/G	
D.C.	D.C.	D.C	D.C	w, x, y
D.C	GEN	D.C	D.C	w, x, y
GEN	D.C	D.C	D.C	v, w, y, z
GEN.	GEN	D.C	D.C	v, w, y, z
LOOP	GEN	DIS.	—	u, w, x, y
GEN	LOOP	–	DIS	s, t, z
GEN	GEN	GEN	GEN	p, q, r, s, z

Fig. 333. Universal Private-Wire Relay Set
(P.M.B.X. 1A.)

signalling in an outgoing direction. The operation of the ringing key in the cord circuit operates relay *RR* which at ***RR*1** and ***RR*2** shunts the 2 μF transmission condenser to reduce the impedance to the outgoing ringing current. ***RR*1** and ***RR*2** also remove *IL* and *LL* from the line to prevent chattering of the latter. On incoming calls the release of *LL* in turn releases *LR* which at *LR*2 prevents the operation of *I* to ringing current. Contact *I*1 is provided to prevent the transmission loss of the shunt path through *RR* during speech.

Universal P.W. Relay Set. The universal private wire relay set (Fig. 333) is a more elaborate circuit employing two additional relays and a transformer type transmission bridge. It is therefore more suitable for use on very long private wires where it is necessary to maintain an accurate balance of the lines. The circuit principles are very similar to those of Fig. 332, but a number of strapping arrangements are provided to meet the various signalling requirements.

The line relay (*LL* of Figs. 332 and 333) requires a minimum signalling current of some 14 mA for satisfactory operation, and hence with a battery voltage of 20 at the P.B.X., loop signalling can be adopted when the line resistance (including that of the distant apparatus) does not exceed 1250 Ω loop. When the line resistance exceeds this figure, single wire d.c. signalling can be adopted up to a line limit of 2500 Ω. Beyond this value generator signalling must be employed. The tabulation (Fig. 333) shows the strapping arrangements for various forms of calling and clearing signals. Relay *LR* is the calling relief relay and is controlled either by *L* or *LL* depending upon the type of calling signal. ***LR*2** lights the calling lamp until *SR* operates, when a plug is inserted into the answering jack. *LD* is the supervisory relay and controls (at *LD*2) the supervisory loop to the cord circuit under the control of one or other of the line relays. With d.c. signalling, for example, relay *LL* is operated for the duration of the call and *LD* is held from the earth at *LL*1 via ***SR*3** and ***LR*3**. *LL* releases when the distant switchboard clears, and at *LL*1 releases *LD*. ***LD*2** now removes the loop to the cord circuit formed via strap *y*.

When the circuit is strapped for generator signalling, the clearing signal momentarily operates relay *L* which, in turn, operates *LD* via ***SR*3** and LR3. ***LD*2** now removes the loop to the cord circuit formed by strap *s* until *SR*2 releases *LD* when the plug is withdrawn. The circuit makes provision for a flashing recall or clearing signal when required. The operation of ***LD*4** starts a common flashing circuit consisting of three interacting relays. A contact of one of the relays alternately makes and breaks the connexion at strap *y* to repeat the flashing signal to the cord circuit.

Miscellaneous Features. The metal rectifier has been introduced across the night alarm relay (*NA*) to prevent overhearing between extensions prior to the operator answering. The *NA* relay is a common impedance to all calling circuits, and, in the absence of the individual impedance of the line relay, overhearing is possible. Fig. 329 shows an impedance coil *I* in the operator's telephone circuit. This coil is placed across the circuit when the speak key is thrown but when relays *SK* and *SKR* are released. This condition exists when the operator enters an established call for monitoring purposes. *I* provides a d.c. loop in these circumstances in order to give a supervisory signal at the public exchange when the operator enters the circuit. The cord test circuit provides not only noise tests on the cord but also gives a functional test to the sleeve and supervisory relays and the supervisory lamps. The P.M.B.X. No. 1A is designed for a local 24 V secondary cell power plant, and provision is made for a ringing lead with a change-over key to the hand generator.

The Keysender. The keysender (Keysender No. 5) is a device introduced as an alternative to the dial on large type private branch exchange switchboards to reduce the time expended by a P.B.X. operator when dialling numbers from the switchboard. By its use, the P.B.X. operator is free to attend to other calls whilst the keysender is still transmitting the digits which have been keyed up. The device is particularly useful in areas such as London where seven digits are required to set up a call.

The keysender (Fig. 334) is a box unit having ten keys of the typewriter pattern which are labelled to correspond with the finger holes of the standard dial. The cover is fitted with a window, through which a disc with lines on its outer edge can be seen. This disc revolves with the pulsing out mechanism and thus serves as a visual indication that the keysender is engaged. Fig. 335 gives a general view of the keysender with the cover removed whilst Figs. 336 to 339 show details of the mechanism. The ten digit keys are pivoted at their rear extremity, and when operated move a storage pawl (*P*1) through an angle which corresponds to the number of the digit. The mechanism is so arranged that the movement of all digit keys is the same, but the different angular movements of the pawl are controlled by a tapered rocker bar (*RP*1). The storage pawl turns a ratchet wheel (*RW*) which rotates about the main shaft. At the end of the movement, a cam (*SC*) attached to the lever

assembly moves a striker plate (*HC*) which engages a marking arm (*MA*) attached to the ratchet wheel assembly. Alongside the ratchet wheel is a fixed ring (*CSR*) carrying 100 steel pins which are held friction tight in holes in the flange of the storage ring by means of a coiled spring. Normally these pins protrude on the marking arm side of the storage ring. When a digit key is depressed, the pawl moves the ratchet wheel round a predetermined distance and the striker plate causes the marking arm to engage a particular steel pin in the storage ring. It is necessary to allow for an inter-digital pause and therefore if, say, key 5 is depressed, a pin is pushed forward $5 + 6 = 11$ pin spaces from the preceding projecting pin. It is possible to store seven consecutive digits by operating various pins along the circumference of the storage ring.

Impulses are sent out by the interruption of impulse springs (*IS*) caused by the rotation of an

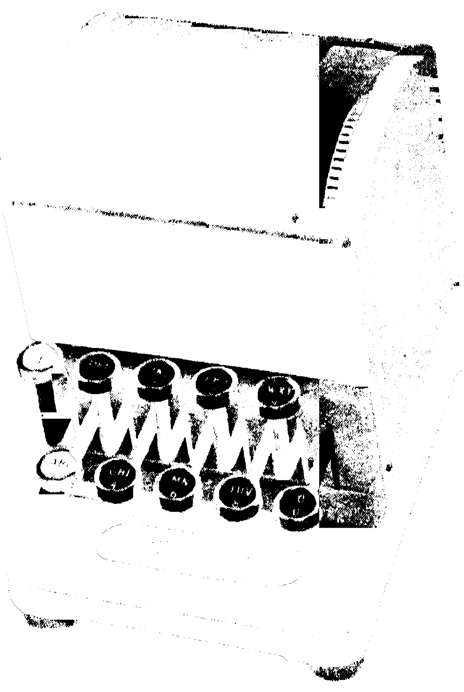


FIG. 334. KEYSENDER (No. 5.)

impulse wheel (*IW*). The impulse wheel rotates about its own axis and in addition rotates about the main shaft, both movements being imparted by means of a star wheel (*SW*) which engages with an internal gear (*IG*) on the storage ring. The storage and sending halves of the mechanism are coupled together by means of a helical clock spring (*S*) which is wound up by the movement of the ratchet wheel during keying. During the rotation of the sending part of the mechanism, a cam (*T1*) associated with the impulse springs brushes over the face of the storage ring bearing against each

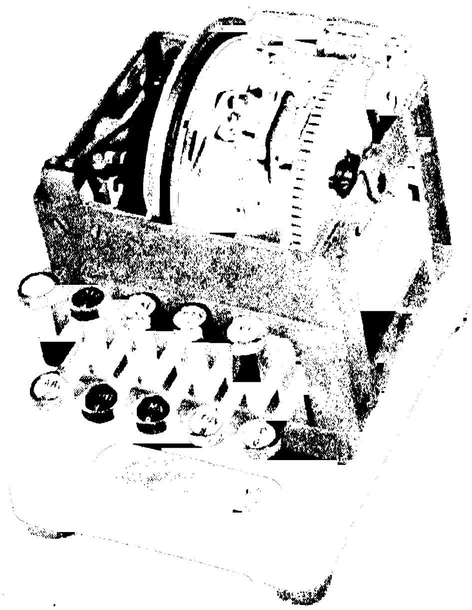


FIG. 335. KEYSENDER WITH COVER REMOVED

projecting pin in turn. Whilst the cam is bearing against a projecting pin the impulse springs are held clear of the impulse wheel. Between marking pins, the cam allows the impulse springs to engage the impulse wheel and the number of impulses thus sent out is determined by the distance between the projecting pins. A tail piece (*T2*) associated with the sending mechanism restores the code pins after the impulsing cam has passed them. On completion of impulsing or when the impulsing cam catches up with the code setting a stop pin (*DP*) fixed to the impulse mechanism engages with a restraining pawl (*P2*) which prevents further rotation when the impulse control cam commences to engage with the last operated code pin. In consequence, the last pin operated is not restored, and thus the mechanism ensures that a train of impulses always starts with a make interval. The impulse wheel, impulse springs, and the governor mechanism (*G*) are similar to those used in the standard dial. The impulse springs are wired to collector rings (*CR*), and connexion is made to the

terminals of the machine by means of phosphor-bronze brushes (*CB*). The mechanism of the key-sender is non-homing, i.e. movement of both the storage ratchet wheel and of the impulse sending unit commences from the point where it finished

restraining pawl turns the internal ratchet in a anti-clockwise direction, thereby holding the off normal springs open. When a code pin has been struck the restraining pawl jumps forward, the pressure on the internal ratchet is relieved, and the

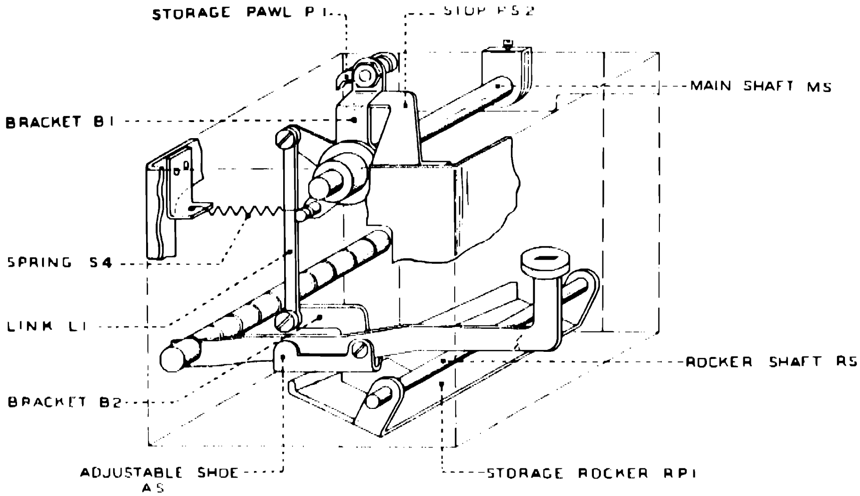


FIG. 336. CODE STORAGE MECHANISM

on the last call. The design of off-normal contact springs is therefore unusual. A plate with an internal ratchet (*IR*) is mounted concentric with the code storage ring and is free to turn through a small angle. The pressure of a stop pin (*DP*) associated with the sending mechanism against a

off-normal springs push the internal ratchet in a clockwise direction and so close. On the completion of impulsing the pressure of the stop pin on the restraining pawl brings the impulse mechanism to rest and opens the off-normal springs.

The keysender is fitted on a small bracket

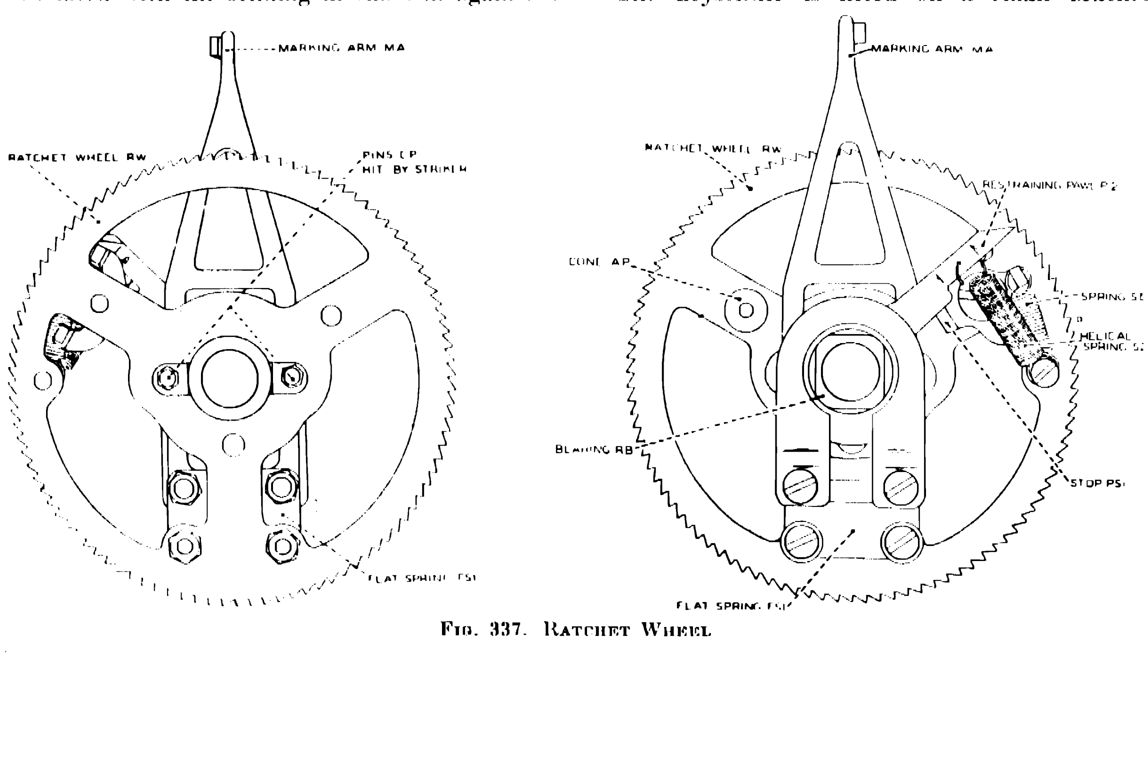


FIG. 337. RATCHET WHEEL

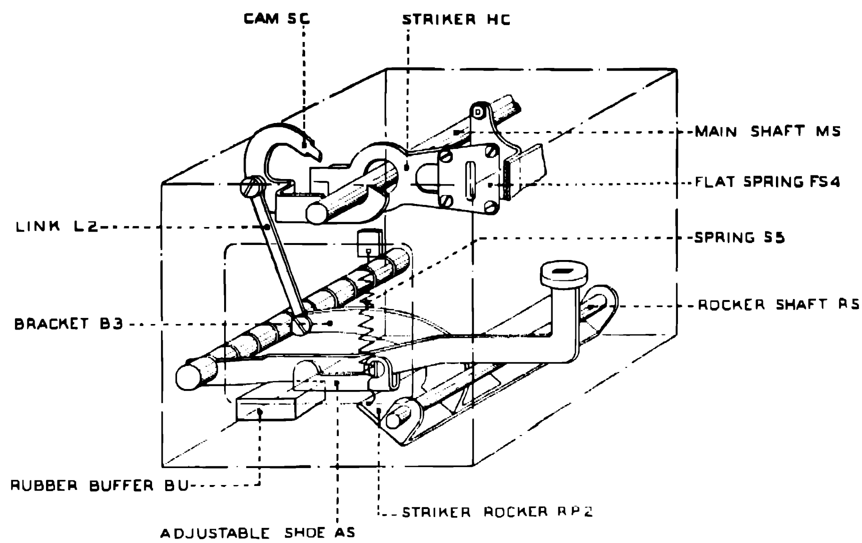


Fig. 338. Striker Mechanism

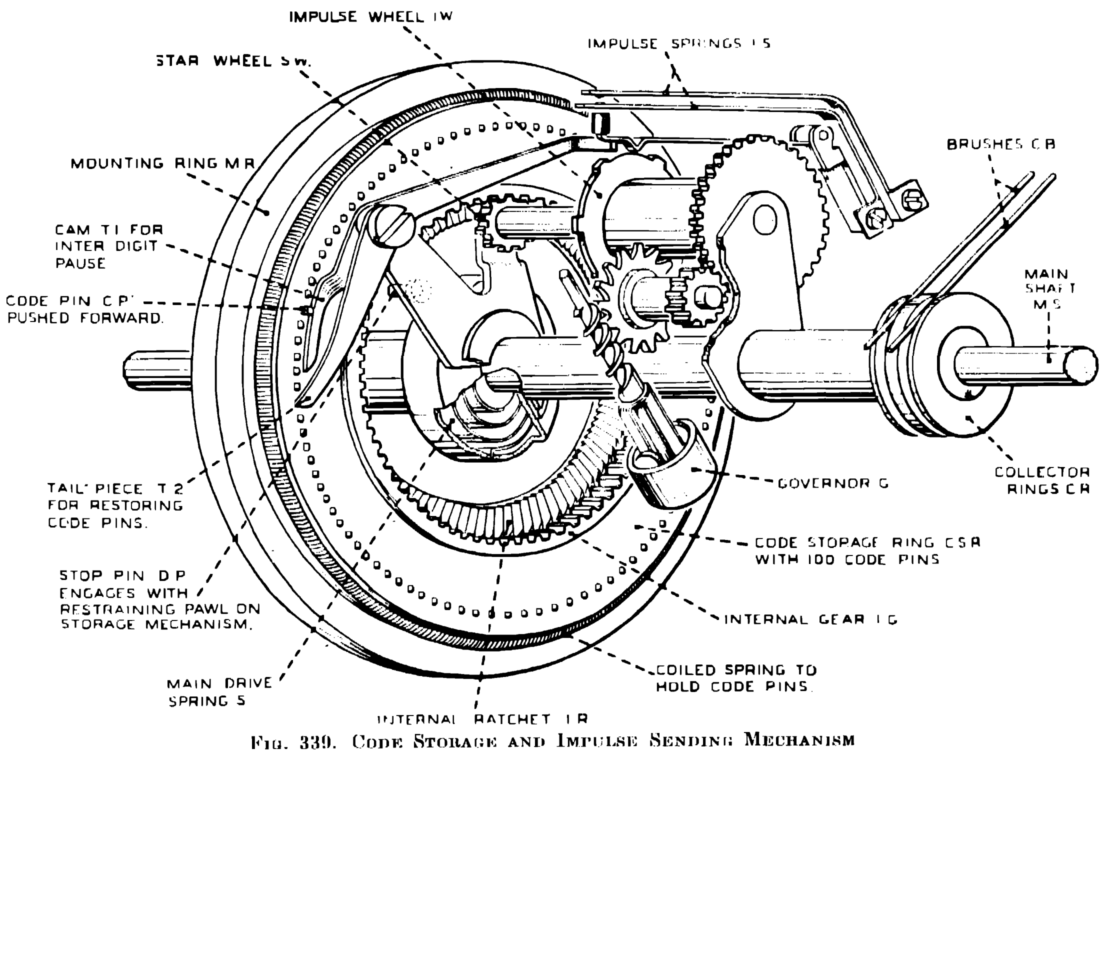


Fig. 339. Code Storage and Impulse Sending Mechanism

attached to the right-hand side of the switchboard. Whenever a keysender is fitted, an emergency dial is held in reserve at the P.B.X. In the event of failure of the keysender the dial is plugged into the switchboard. The circuit arrangements are as shown in Fig. 340. Additional contacts are provided on the cord circuit dialling keys and a relay

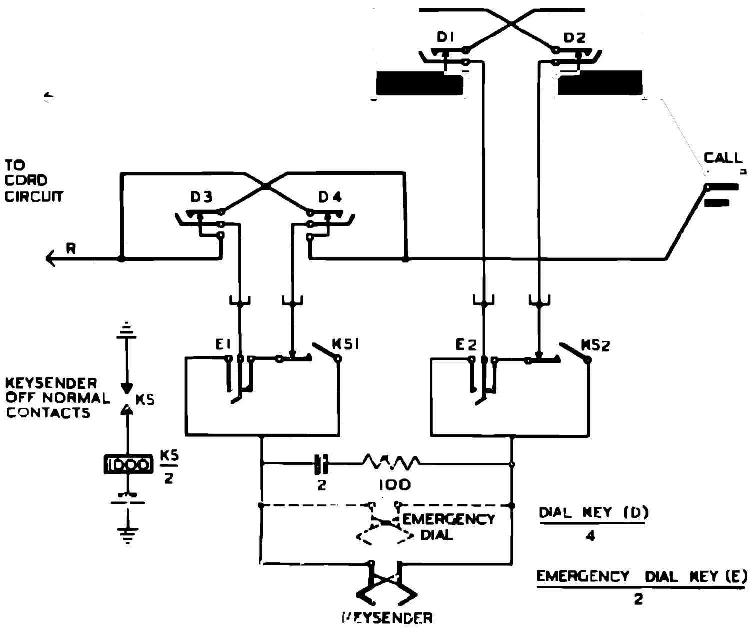


FIG. 340. CONNEXION OF KEYSENDER TO CORD CIRCUIT

is introduced into the keysender circuit so that at the completion of pulsing out, the cord circuit is restored to normal without the necessity of immediately restoring the dial key. An emergency dial key is provided to change over from the keysender to the emergency dial when necessary.

The House Exchange System. The House Exchange system combines the facilities of the earlier house telephone system with direct access from the stations to the public exchange. It was introduced several years ago to meet the requirements of subscribers who would otherwise be faced with the installation of a private intercommunication system to cater for a large internal traffic together with a public service telephone or private branch exchange. The following facilities are standardized for the system:

(1) The same instrument is used irrespective of the type of public exchange. This instrument is designed on C.B. principles and, where a house exchange system is required in conjunction with a magneto or C.B.S. public exchange, special conversion units are fitted at the public exchange.

(2) There are two arrangements of equipment to cater for:

(*a*) One exchange line and a maximum of six extensions (including one external extension).

(*b*) Two exchange lines with eleven extensions (including one external extension).

Both instruments have the same general appearance but the number of press buttons differs.

(3) Any instrument of the system may be used as the master station. An auxiliary unit is fitted at the master station, which provides calling indicators for the exchange lines and for an external extension (when fitted).

(4) In order to cater for times when the master station is unattended, a second choice master station may be provided by the fitting of a similar auxiliary unit at the selected second choice station. A transfer key fitted on the first choice main station switches the exchange and extension calling signals to the second choice station.

(5) Exchange calls are secret and cannot be overheard by any of the extensions on the system. By suitable strapping, however, supervision on exchange lines may be given to any selected station.

(6) An engaged test is provided on "busy" exchange lines.

(7) An exchange line may be held whilst a second call is made on another exchange line or on an internal extension.

(8) Exchange calls (which are normally answered at the main station) may be transferred direct from one station to another. This facility is also available for originated exchange calls.

(9) The master station is provided with trunk offering facilities where the required extension is speaking on a local call.

(10) Exchange calls may be entirely barred to any specified station, or alternatively exchange calls may be allowed only at the discretion of the master station.

(11) The system provides for direct calling and clearing from any station to the exchange.

(12) Local calls are non-secret.

(13) Conference facilities are provided so that any number of stations may be connected together.

(14) Apart from the night service facilities provided by the second choice main station, the

external extension may be allowed direct access to the exchange line under night service conditions.

(15) The equipment provides for the provision of extension bells from any instrument.

Apparatus. The house exchange instrument *Telephone Intercommunication No.* 2) is illustrated to give the maximum accessibility to all parts for maintenance purposes. The complete button mechanism may be removed as a unit leaving in situ the spring banks and cabling. Each spring bank is removable as a unit and the relays (which are of the 600-type) are mounted on separate

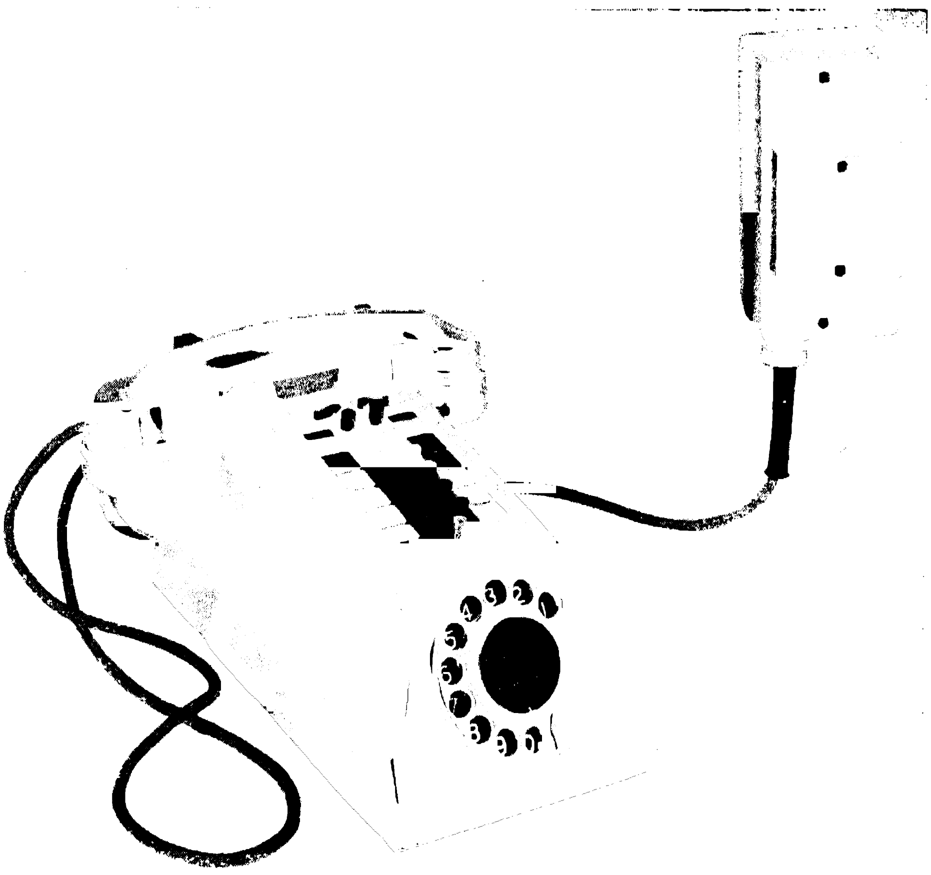


FIG. 341. HOUSE EXCHANGE INSTRUMENT
(Telephone intercom. No. 2.)

in Fig. 341. The design follows similar lines to that of the standard one-piece instrument described in Chapter IX, but has in addition the required press buttons for establishing local calls. The instrument illustrated has two exchange line buttons, ten extension buttons, a conference button and a small trigger key associated with each exchange line. The instrument provided on smaller installations employs the same standard casework but only one row of keys (i.e. one exchange, five extension, and one conference). Figs. 342 and 343 show the internal arrangements of the telephone from which it will be noted that the lay-out has been designed brackets so that they can readily be swung clear of the mechanism for adjustment purposes. The calling buzzer is dissociated from the telephone and is incoprorated in the external connecting block in order to facilitate adjustment without interference with the instrument proper. A further feature is that the connecting block is made in the form of a plug and jack so that the complete instrument may be removed at will.

An auxiliary unit known as a *Unit Transfer Intercommunication* is required at the main station (i.e. that chosen to answer exchange calls). The unit accommodates the exchange line calling

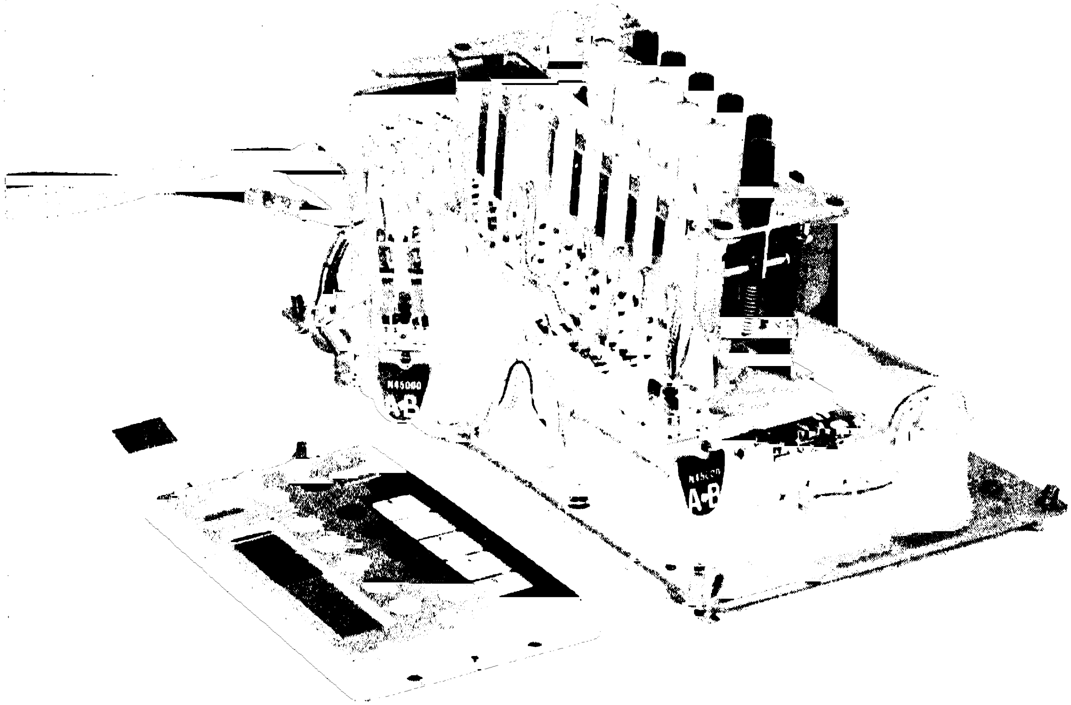


Fig. 342. House Exchange Instrument
Chassis removed from case.

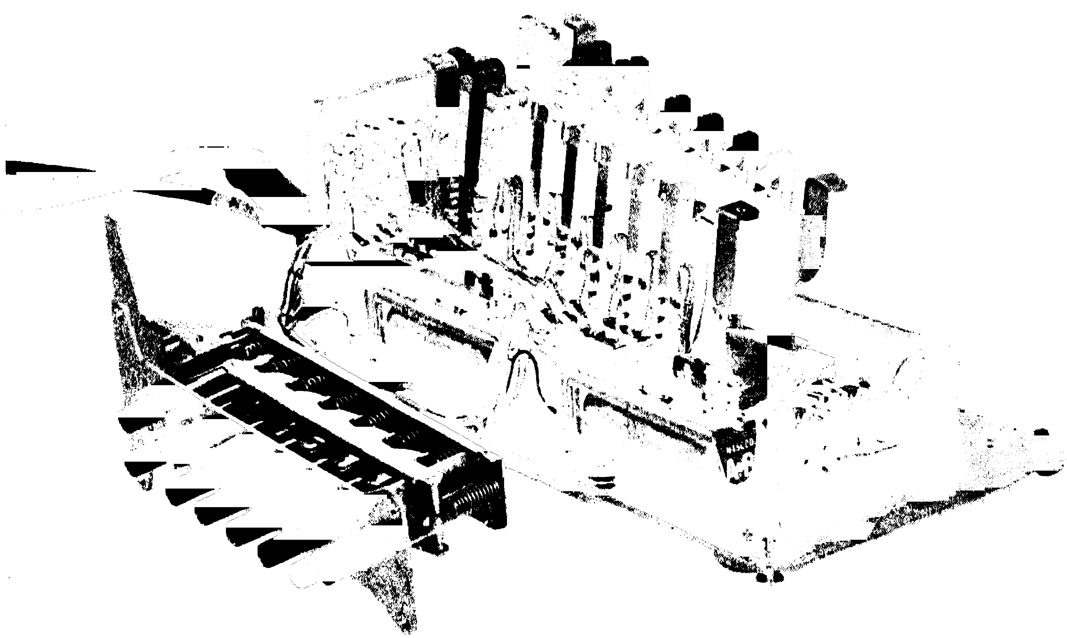


Fig. 343. House Exchange Instrument
Chassis with press-buttons detached.

indicators, the external extension indicator and the associated keys. The facilities provided vary with different installations but all conditions are met by the use of one of four standard designs (Nos. 1, 1A, 2, and 3). All the four units are similar in appearance, but the number of calling indicators and keys varies. Fig. 344 illustrates Unit Transfer Intercommunication No. 1A which accommodates eyeball indicators for one exchange line and one external extension together with a transfer key, the exchange to extension key, and the night service key.

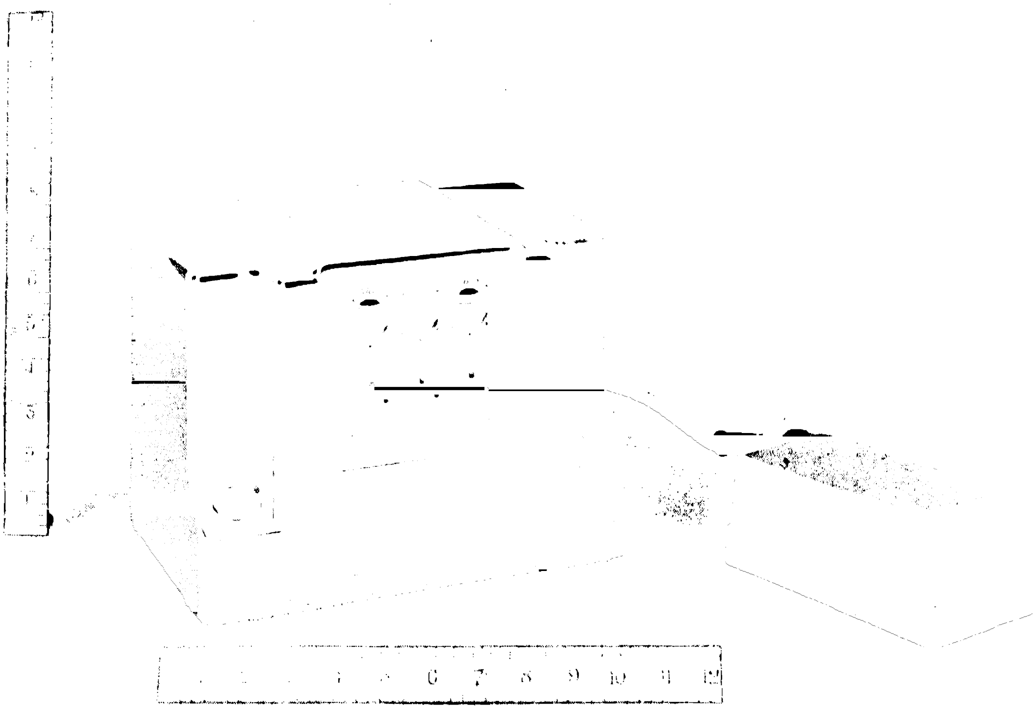


FIG. 344. TRANSFER UNIT
(Unit transfer intercom. 1A.)

Circuit Description—Internal Calls. Figs. 345 and 346 show complete circuits for a 1 + 5 type intercommunication telephone and for a Transfer Unit (No 1A) suitable for use at a main station where there is one exchange line and an external extension. Fig. 347 shows the circuit elements involved on local station to station calls with the exchange line switching details omitted for clarity.

To call any internal extension, the originating station removes the microtelephone thereby allowing the *HM* springs to operate, and then fully depresses the local key adjacent to the number of the required extension. Springs ***CB*** and ***L*** are thereby operated and an earth is extended from ***HM2*** via ***CB2*** to the *B*-line of the required extension. Contacts ***CB1*** extend the buzzer *BZ* to the common wire. If the called extension is free, the earth placed on the *B*-line is extended to the *R*-wire of the called extension circuit and thence via *HM*1 to the buzzer. The called extension's buzzer is therefore actuated for the period during which the caller has the appropriate local button fully depressed. When the called extension answers by removing the handset from its rest, the ***HM*** springs operate and the telephone circuit is connected to the *HL* and *R* wires via ***HM1***, the buzzer circuit being disconnected at the latter contacts. When the caller's finger is removed from the local key, the latter partially restores to the speaking position. The *L* springs remain operated in this position, but the common bank spring set (*CB*) is released. A separate transmitter feed bridge is provided for each telephone by the application of earth at ***HM2*** via *RA* to the *A*-line and a battery through the remaining coil of *RA* via ***HM1*** to the *B*-line. If the called extension is engaged on a call to another extension, the earth on the *R*-wire incoming from the calling extension will not operate the buzzer at the called extension due to the disconnexion at ***HM1***. When the local key on the calling extension's

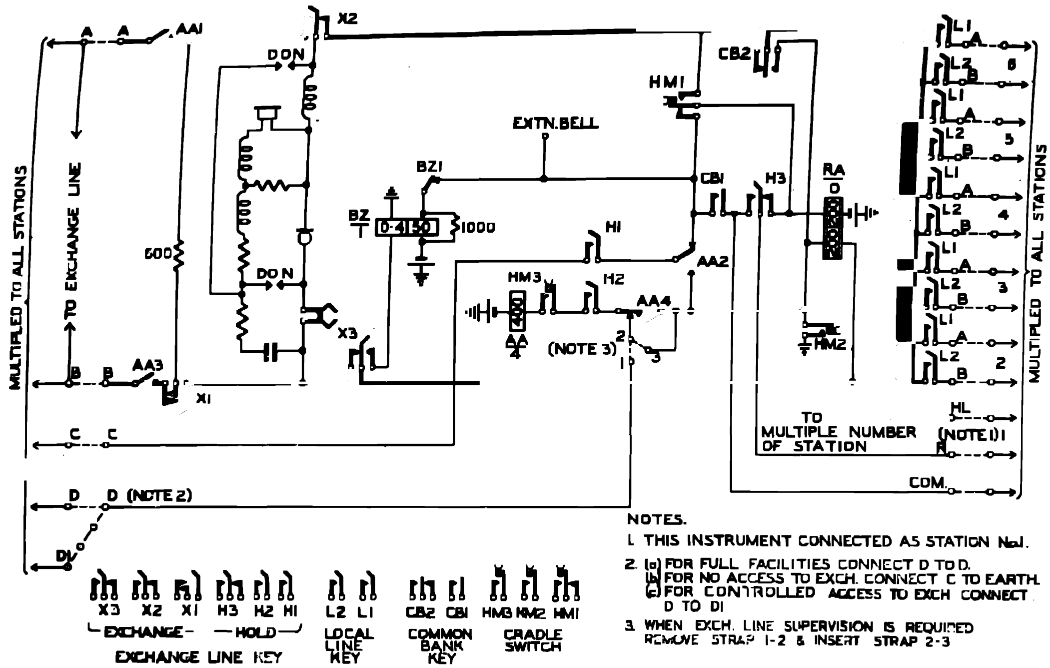


Fig. 345. Circuit of Five-station House Exchange Instrument

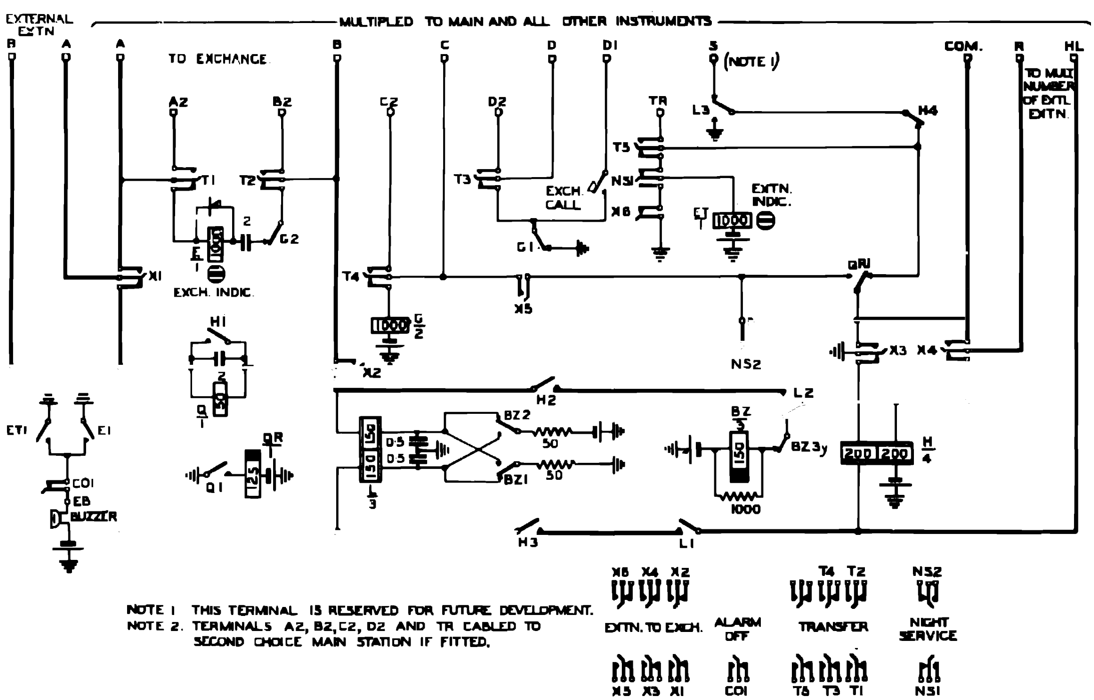


Fig. 346. Circuit of Transfer Unit

(No. 1A.)

telephone set restores to the speaking position, however, the telephone circuit is connected to the *A*- and *B*-wires as described above. A caller is therefore able to break into any connexion between two other local extensions. If the called extension is engaged on an exchange call, the hold springs (*H*) on the appropriate exchange key will be operated and at ***H*3** the *R*-wire will be connected to the common (Fig. 348). When the caller fully depresses the appropriate local key the earth placed on the *R*-wire of the called extension is returned to the calling station on the common wire and operates the caller's own buzzer via ***CB*1**. On the termination of a call all keys are restored mechanically to their normal position by the replacement of the microtelephone on the rest.

Internal Extension Calling External Extension. When the calling extension removes the microtelephone from its rest and fully depresses the appropriate local key an earth is extended to the *B*-line in the usual way. This earth is received on the *R*-wire of the external extension circuit and operates relays *H* and *BZ* in the Transfer Unit at the main station (Fig. 347). ***H*2** and ***H*3** extend the *R* and *HL* wires, and ***H*4** disconnects the external extension indicator in readiness for the operation of relay *L*. ***H*1** similarly shortcircuits relay *Q* which is not required on this call. If the external extension is free, relay *BZ* alternately operates and releases by breaking its own circuit at ***BZ*3*y***. ***BZ*1** and ***BZ*2** reverse the earth and battery connexions to relay *L* and thence to the external extension instrument. These reversals of potential across the bell of the extension instrument are the equivalent of normal alternating ringing current and energize the bell in the usual way. During the ringing period the 0·5 μF condensers act as a spark-quench to contacts *BZ*1 and *BZ*2. Relay *L* does not operate until the external extension answers and a d.c. loop is provided. If the calling party takes his finger from the external extension button before the external extension answers, *H* continues to hold from its own battery via the loop of the calling extension and the second coil of *H* to earth. Relay *BZ* is designed not to hold under these conditions, and therefore removes the ringing current from the external extension line. The operation of *L* when the external extension answers disconnects relay *BZ* and switches through to the calling line at ***L*1** and ***L*2**. ***L*3** is ineffective due to the previous operation of ***H*4**.

If the external extension is engaged on a local call the operation is similar except that relay *BZ* cannot operate due to the disconnexion of its circuit at ***L*2**. If, however, an external extension is engaged on an exchange call spring *X*4 will be operated, thereby connecting the *R*-wire to the common (Fig. 348). Thus, when a caller fully depresses the local button his own buzzer will operate as described previously.

External Extension Calling Internal Extension. It is not possible on economic grounds to extend the main multiple of the internal stations to the external extension. There are therefore only two wires between the external extension instrument and the main station, and it is not possible to give the external extension the facility of direct access to all internal extensions. All such calls are obtained via the main station. When the external extension lifts his receiver from the rest relays *L* and *Q* operate from the battery and earth at *BZ*1 and *BZ*2 via the loop of the calling telephone. Relay *Q* (Fig. 346) has no function, but contact ***L*3** completes the circuit for the extension indicator and ***L*1** and ***L*2** prepare for the extension of the calling line to the main instrument. An audible alarm is provided from the local contacts of the extension indicator. The main station answers by removing the microtelephone and depressing the local key corresponding to the external extension number. The telephone loop of the main station is thereby connected to the *A* and *B* multiple wires of the external extension which are strapped to the *R* and *HL* wires of the Transfer Unit. The loop therefore operates relay *H*. ***H*1** short-circuits the *Q* relay, whilst ***H*2**, and ***H*3** complete the circuit to the external extension. ***H*4** disconnects the external extension indicator circuit.

After ascertaining that an internal extension is required the main station calls the required extension in the usual way and the called extension upon answering is requested to call the external extension. The main station operator then replaces the microtelephone.

Conference Facilities. If a conference of several internal extensions is required, the main station calls each of the required extensions individually and each extension is advised to "hold on." When all required extensions have been called the conference button is pressed and each individual local station button is pressed for the second time. The mechanical arrangements are such that when the conference button has been pressed it is possible to press consecutive local buttons and leave them in the operated position until such time as the microtelephone is replaced on the rest. If a mass call were made instead of first calling the extensions individually, as soon as one station answered the buzzers at all the other called extensions would continue to operate until answered, even although the caller had removed pressure from the local keys. The earth from ***HM*2** of the first telephone to

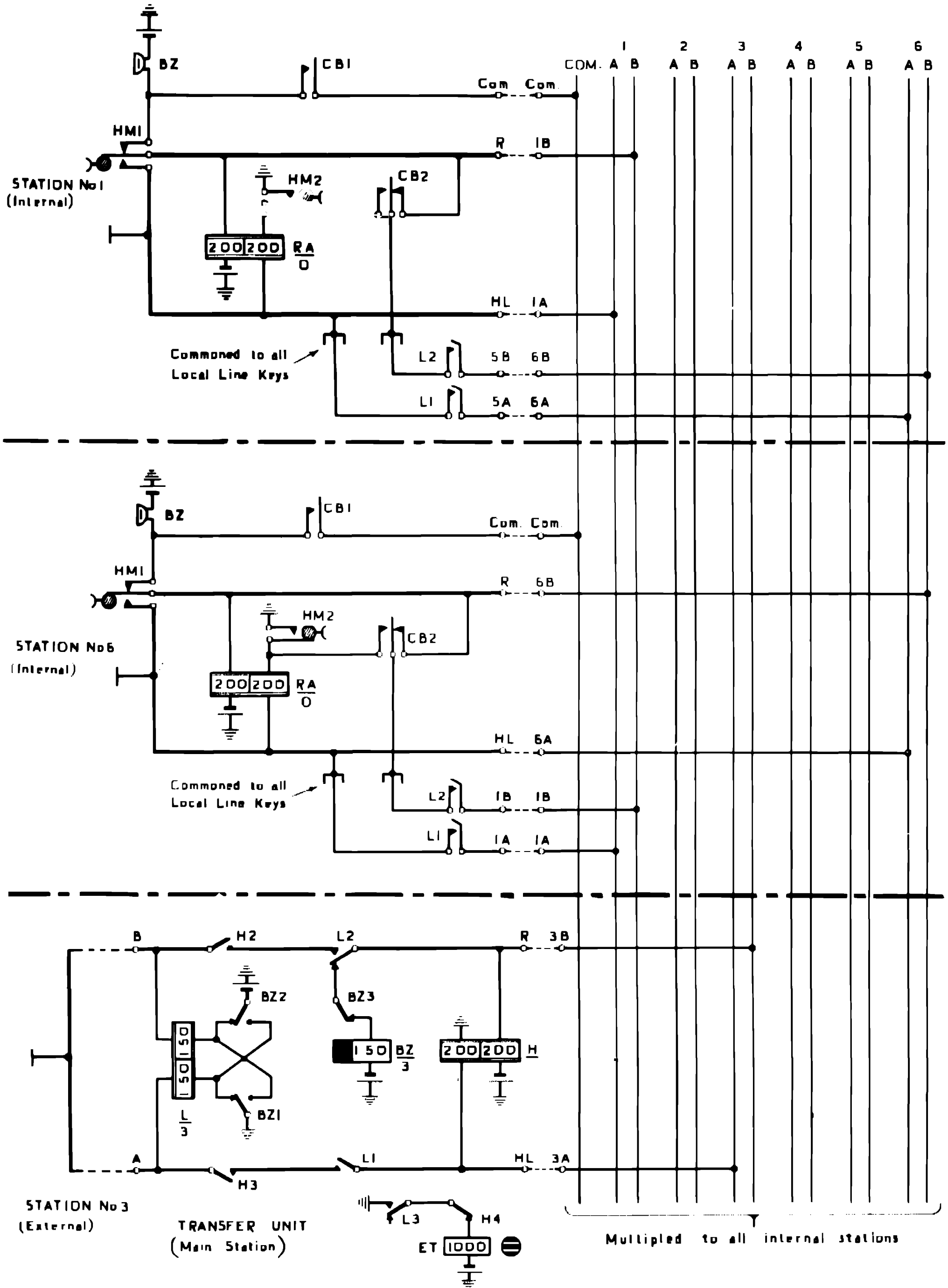


FIG. 347. CIRCUIT ELEMENTS FOR STATION-TO-STATION CALLS
House exchange system.

answer is extended via the coil of *RA* to the *B*-lines and buzzers in parallel. Continuous operation of the buzzer until an extension answers is undesirable, and in the operating instructions it is laid down that a mass call should be made only after it has been ascertained that a person is in attendance at all the called extensions.

Internal Extension Calling the Exchange. Fig. 348 illustrates the switching elements for exchange calls. It will be noted that, in addition to the *A*- and *B*-wires of the exchange line, three control wires (*C*, *D*, and *D*1) are multipled to all internal stations. To call the public exchange the internal extension station removes the microtelephone thereby operating the *HM* contacts. He then depresses the exchange key, thus operating the *X* and *H* springs. These spring piles are mechanically so arranged that the *X* units can be released by the depression of any other key on the telephone. The *H* springs, however, are not released when a second key is depressed but can only be restored either by the replacement of the hand microtelephone or the operation of the trigger key associated with the exchange line in question. Contacts ***H*3** disconnect the buzzer circuit from the *R*-wire and loop the latter to the common wire, thereby providing an engaged test to any callers. If the exchange line is free, relay *AA* operates via ***HM*3**, ***H*2**, and the *D*-wire of the multiple to the earth at *G*1 in the Transfer Unit. A locking circuit is provided for relay *AA* at ***AA*4**. ***AA*1** and ***AA*3** extend the telephone loop (via ***X*1** and ***X*2**) to the exchange line. ***AA*2** similarly extends the earth from ***HM*2** via ***H*1** to the *C*-wire of the multiple. This earth operates relay *G* in the Transfer Unit. *G* in turn removes the earth from the *D*-wire at ***G*1** in order to engage the exchange line to all other callers. ***G*2** removes the exchange indicator from across the speaking circuit. The call is set up in the usual manner and release is effected by the restoration of the *X* and *H* spring sets when the microtelephone is replaced.

If the exchange line is engaged, the absence of earth on the *D*-wire prevents the operation of relay *AA*, whilst the presence of an earth on the *C*-wire (from the ***HM*2** contacts of the engaging telephone) operates the local buzzer of any testing instrument via contacts ***H*1** and *AA*2.

External Extension Calling Exchange. To gain access to the exchange line the external extension must first call the main station. The main station, having ascertained that an exchange call is required, proceeds to test the exchange line by depressing the exchange line key on the main instrument. If the line is free, it is switched to the external extension by throwing the "extension to exchange" key on the auxiliary unit. Contacts ***X*3** and ***X*5** operate relay *G* and, at the same time, apply an engaging earth to the *C*-wire of the multiple. ***G*1** as usual prevents access to the exchange line by other parties. The main station now replaces the microtelephone and the external extension is extended to the exchange line at ***X*1** and ***X*2**, whilst relay *Q* operates in series with the loop. A slow-to-release relief relay *QR* is introduced so that contacts ***QR*1** do not respond to the dialled impulses during the setting up of a call. At the end of the call, through clearing from the external extension is provided by the release of *Q* and *QR*, whilst the restoration of *QR*1 operates the extension indicator as a clearing signal. The main station now restores the "extension to exchange" key.

Incoming Exchange Call. All incoming exchange calls are received at the main station. The exchange indicator (*E*) is of the doll's-eye type and is shunted by a metal rectifier to give continuous operation from the received alternating ringing current. Local contacts of the exchange indicators provide an audible alarm. The main station answers by removing his microtelephone and depressing the appropriate exchange key. If the call is to be extended to an internal extension, the main station depresses the local key corresponding to the number of the extension required. This operation mechanically restores the exchange line key to the hold position but the *H* springs remain operated. The exchange line is now held by the 600 Ω resistance. The called extension is requested to pick up the exchange line by depressing the appropriate exchange key at the extension station. Due to the fact that the exchange line is engaged the buzzer at the extension will operate as described previously, and tone is passed back to the main station from the 0·4 Ω coil of the extension buzzer via ***X*3**, the *A*-wire and the appropriate ***L*1** springs to the telephone circuit. On receipt of this tone the main station replaces the microtelephone on its rest, which restores all keys to normal and removes the busy conditions from the *C*- and *D*-wires. The *AA* relay at the extension station now operates to earth on the *D*-wire and so connects this extension to the calling exchange line. If the required extension is engaged on a local call, the main station can break into the connexion (there is no secrecy) and offer the exchange call to the extension concerned. If the call is destined for the external extension the main station calls the latter by depressing the appropriate local key, the exchange line being held meanwhile. The external extension is advised that an exchange call is waiting and the main station then throws the appropriate extension to exchange key.

An exchange call can be transferred from station

to station if desired in exactly the same way, with the one exception that an exchange call cannot be transferred direct from an internal extension to an extension flashes the main station and the latter carries out the transfer.

On installations with two exchange lines it

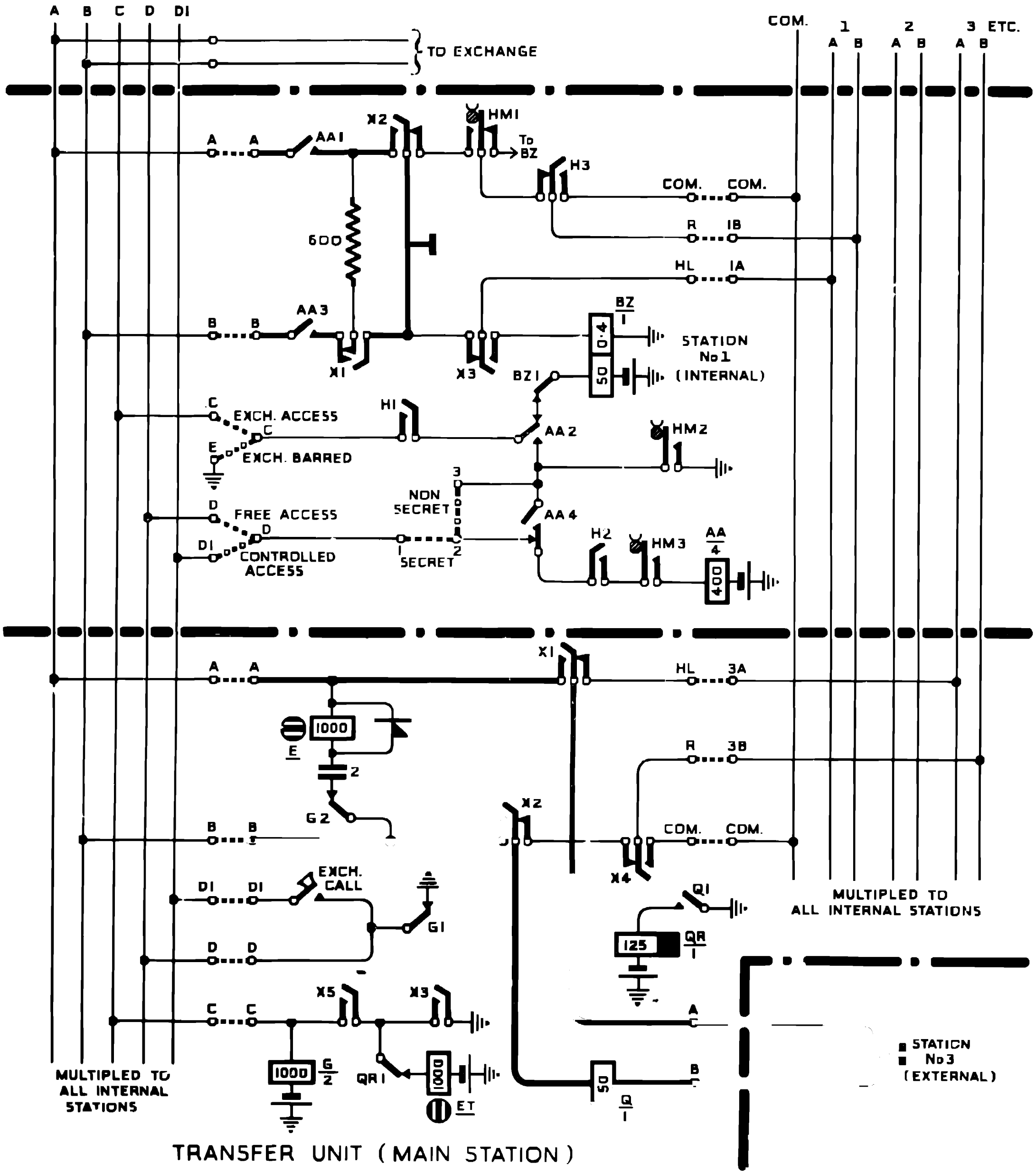


FIG. 348. CIRCUIT ELEMENTS FOR EXCHANGE LINE CALLS
House exchange system.

external extension except via the main station. If it is desired to transfer a call from an external extension to an internal extension, the external sometimes happens that the main station is talking on one line and a call is received on the second line. The main station may temporarily abandon the

ll on the first line and by depressing the second xchange key may accept the call on the second line. This second call can then be transferred to some other station. In these circumstances it is necessary for the main station to release his hold on the second exchange line but at the same time to maintain the holding condition on the first exchange connexion. To enable this to be done a special trigger key is provided so that by operating this key it is possible to release one exchange line without releasing the other.

Exchange Calls Barred. Any internal extension may be barred the facility of direct access to the exchange line (Fig. 348). This facility can readily be provided by disconnecting the *C*- and *D*-wires of the instrument from the multiple. The *C*-wire of the instrument is then earthed and the *D*-wire is left disconnected. The depression of the exchange line key will thus always encounter engaged condition. More often it is desirable to arrange that an extension shall not have unrestricted access to the exchange, but exchange calls may be allowed at the discretion of the main station operator. At these extensions the *D*-wires of the instruments are cross-connected at the junction box to the corresponding *D*1-wires and not to the *D*-wires as usual. The *D*1-wire is normally disconnected from earth, but by the operation of a press button labelled "Exchange Call" situated on the main station unit the *D*1-wire may be temporarily earthed and thus allow the *AA* relay to operate on the exchange barred extension. To make an outgoing call, therefore, the extension first calls the main station in the normal way. If an exchange call is to be allowed the main station operator tests and engages a free exchange line. The extension is then instructed to depress the appropriate exchange key and on receipt of buzzer tone from the extension, the main station operator holds down the appropriate Exchange Call button and at the same time replaces the main station microtelephone.

Monitoring Exchange Calls. Secrecy is normally given on exchange calls. Monitoring facilities may, however, be allowed at the main station or at any of the internal extensions. By removing the strap between terminals 1 and 2 in the *D*-wire circuit (Fig. 348) and inserting a strap between terminals 2 and 3 it is possible to provide monitoring facilities from that instrument. Under these conditions the lifting of the microtelephone and the operation of the exchange key provides an operate circuit for *AA* independent of the condition on the *D*-wire, and thereby enables the caller to break into an engaged exchange line.

Second Choice Main Station. By the operation of a key labelled "Transfer" at the first choice main station unit, the functions of that station may be transferred to the second choice main station. The spring units of the transfer key (***T*1, *T*2, *T*3,** and ***T*4**) extend the *A*-, *B*-, C-, and *D*-wires to the second main station unit (Fig. 346). ***T*5** extends the extension indicator circuit in a similar manner. The second choice main station can then carry out

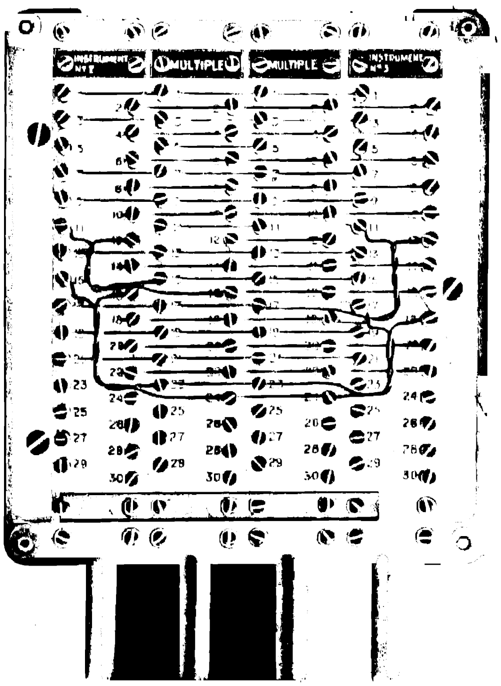


FIG. 349. HOUSE EXCHANGE JUNCTION BOX

the normal duties of the first choice main station. Arrangements are not provided, however, for the switching of the extension-to-exchange key leads and if the external extension requires a call it is necessary for the operator at the second choice main station to go to the first choice main station.

Night Service. The external extension station may be permanently switched to an exchange line at night by the operation of the extension-to-exchange key and the night service key on the main station unit. The operation of the former key gives the external extension direct access to the exchange and the night service key prevents the operation of the extension indicator and of the local audible alarm. The ***NS*2** contact prevents the *C*-wire of the multiple from being permanently earthed so that the exchange line will test free to an

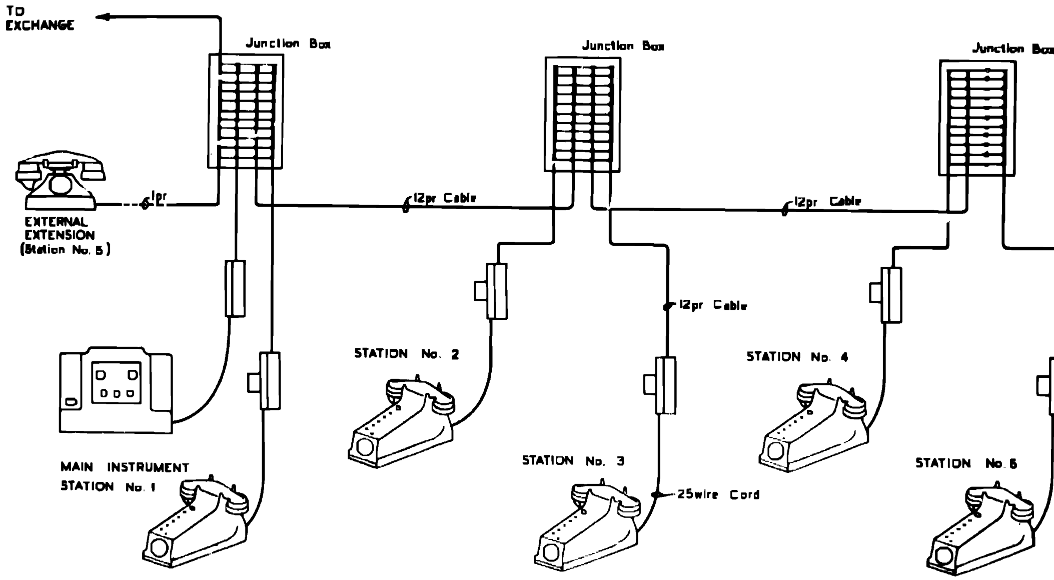


FIG. 350. TYPICAL CABLING ARRANGEMENTS OF HOUSE EXCHANGE SYSTEM

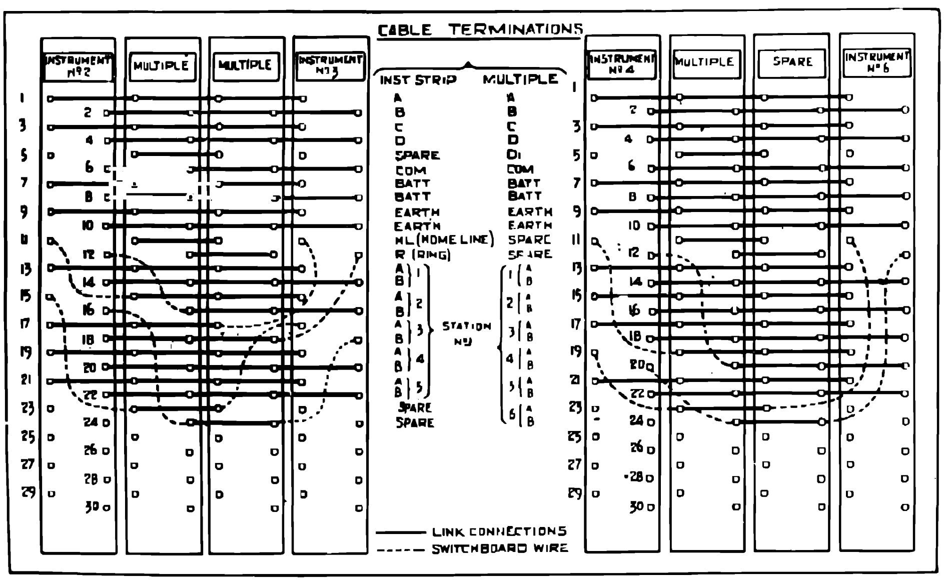


FIG. 351. HOUSE EXCHANGE SYSTEM

Cross-connexions at Junction Boxes for Stations 2, 3, 4, and 6

ternal extension when it is not in use by the xternal extension.

Cabling. In addition to the special plugs and jacks of the instruments themselves, junction boxes are provided for the termination of the multiple cables and on which the necessary cross-connexions can be made. These boxes are made up in two sizes, 30-way and 48-way, the former being used throughout the five-line system and also as an auxiliary box when required on the ten-line system which is normally served by the larger size.

The arrangements of a typical 30-way junction box are shown in Fig. 349. In this illustration separate strips are utilized for the incoming and outgoing multiple cables and two further strips are connected to instruments Nos. 2 and 3. It is a feature of the house exchange system that all cables are terminated on individual terminal strips, and the necessary commoning is done by means of square-section bare wire. When other cross-connexions are required they are carried out in switchboard wire.

Two sizes of cable have been standardized—a 12-pair cable for the five-line system and a 20-pair cable for the larger system. The conductors are of No. 23 S.W.G. and are tinned and enamelled, with an outer covering of two lappings of cotton laid on in opposite directions. Standard colours are utilized for the outer cotton lapping, and a helical lapping of white tape is laid over the outer layers of the conductors. The whole cable is waxed and lead sheathed. The use of twisted pairs throughout in a system of this kind is essential if crosstalk is to be avoided. A typical cabling lay-out for a six-station installation is shown in Fig. 350, whilst Fig. 351 shows, in more detail, the cross-connexions in two of the junction boxes. This lay-out may be considerably varied to suit the individual lay-out of stations. The cross-connecting of a $10 + 2$ system follows the same principle as that of the five-line except that at the main station it may be necessary to have a 30-way auxiliary junction box in addition to the 48-way main box owing to the number of cables to be accommodated.

Power Supply. The power for a house exchange system is normally obtained over a power lead from the public exchange (Chapter XX), but where this is not practicable a battery of primary cells or a trickle-charged secondary cell installation may be employed. The system is designed to operate with a nominal 24 V, but the factor of safety is sufficient to permit its use on any voltage between 18 and 28 V. The maximum current consumption is approximately 1·3 A for a fully equipped $10 + 2$ installation. A 10 μF condenser should be connected across the power lead in order to reduce to a minimum any crosstalk due to battery feed resistance.

EXERCISES XI

1. State the advantages and disadvantages of providing through clearing facilities at subscribers' private branch exchanges.

Describe, with the help of circuit diagrams, the way in which through clearing is provided:

(*a*) On cordless switchboards, and

(*b*) On double cord switchboards at private branch exchange installations.

(*C. & G. Telephony, Grade II*, 1940.)

2. Show by means of circuit diagrams what happens when the Night Service key of a 25-line P.M.B.X. is operated.

3. Explain why, on a 65-line P.M.B.X., a clearing signal is not given to the exchange whilst a call is being extended to an extension and before the extension replies.

4. Compare the supervisory signal arrangements of a 25-line and a 65-line P.M.B.X.

5. Describe, with the help of simplified diagrams, the stage by stage progress of an extension to exchange call on a P.M.B.X. No. 1A.

6. Explain what happens if, on a P.M.B.X. No. 1A, an exchange line is taken into use for an incoming call before the previous connexion has been taken down by the P.M.B.X. operator. Draw the circuit elements concerned.

7. Describe the main features of switchboard equipment suitable for a large private manual branch exchange at which multiple facilities are required. Give diagrams of the line and cord circuits. Assume that the exchange lines are connected to an automatic exchange. (*C. & G. Telephony, Grade I*, 1941.)

8. Give a diagram and explain the salient features of the terminal equipment at a P.M.B.X. No. 1A, on a d.c. signalling private wire.

9. Enumerate the facilities provided by the House Exchange System.

10. Explain with simple diagrams how an incoming exchange call is passed to an internal station of a House Exchange installation.

11. Give the circuit elements of a House Exchange system by means of which:

(*a*) A station can be given free access to the exchange line.

(*b*) A station can be barred access to the exchange line.

(*c*) A station can have access to an exchange line only after receiving the permission of the main station.

(*d*) A station can monitor any exchange call.

CHAPTER XII

THE CIRCULATION OF PUBLIC TRAFFIC

In order that any one subscriber can be connected as required to any other subscriber in the telephone system, a network of inter-exchange circuits is necessary. There are at present some 5700 exchanges of all types in the United Kingdom, and it is obviously impracticable to provide lines between each exchange and every one of the remaining exchanges to cater for the possibility of demands which on some routes may be very occasional. In general, direct circuits between two exchanges are provided only when the volume of traffic justifies such provision. In all other cases calls are established through one or more intermediate exchanges.

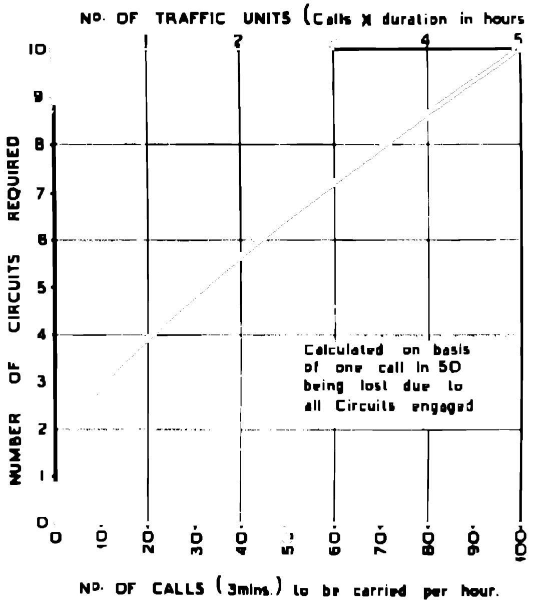


FIG. 352. CIRCUITS NECESSARY TO CARRY DIFFERENT VOLUMES OF TRAFFIC

It is interesting to note that, for a given standard of service, the traffic-carrying capacity of each circuit in a large group is greater than the capacity *per circuit* of a small group. This principle is discussed in more detail in Volume II in connexion with automatic switching but it can, at this stage, be readily demonstrated by the curve of Fig. 352. It would appear at first sight that one circuit would carry, in any one hour, traffic equivalent to twenty calls each of three minutes duration. If the twenty calls originated one at a time and at exactly three minute intervals, then one circuit could be fully loaded. This is, however, by no means true under practical conditions when the traffic originates in a pure chance manner, with three or more calls in rapid succession followed by periods of no traffic. It is apparent that, to occupy fully any one circuit, an infinite number of originated calls are required to ensure that a call is always available at the moment the circuit becomes free. This, in turn, would result in an infinite number of calls which could not be completed due to the circuit being engaged. In practice, therefore, any circuit or group of circuits will carry only a fraction of the theoretical maximum traffic, the exact amount of traffic carried being dependent upon the permissible number of calls lost or delayed due to the circuits being engaged.

Fig. 352 shows the standard basis of provision for circuits which form the "basic" links of the inter-exchange network. The figures are calculated on the assumption that one call in fifty is lost due to insufficiency of circuits. A less generous provision of circuits on the basis of one lost call in thirty is adopted for less important routes which are not part of the main network.

It will be noted from Fig. 352 that three circuits are required to carry the traffic equivalent to ten three-minute calls per hour, whilst four circuits will carry twice this volume of traffic. Similarly, six circuits will carry more than eight times the traffic carried by a group of two circuits. It will be observed, however, that as the size of the group increases, the rise is less pronounced. An extension of the curve would show that there is very little to be gained by increasing the size of a group beyond twenty or thirty circuits. To summarize, groups of less than five circuits are very inefficient and should be avoided wherever possible. On the other hand, very large groups of circuits introduce operating difficulties and do not produce a material increase in traffic efficiency.

The above principles are illustrated in Fig. 353 which shows three hypothetical exchanges *A*, *B*, and *C* with interconnecting circuits. At (*a*) individual groups of circuits are provided and on this basis the assumed traffic requires four circuits between *A* and *B*, three circuits between *A* and *C*, and five circuits between *B* and *C*. It is apparent that a material increase of efficiency can be obtained

routing calls between A and C via exchange B. (Fig. 353 (b).) Five circuits between A and B, together with six circuits between B and C, will now carry all the traffic between the three exchanges. Thus an increase of one circuit on the AB, BC routes avoids the provision of three very much longer circuits from A to C.

Apart from the greater efficiency obtainable, the concentration of circuits into large groups also reduces the capital cost and maintenance charges per line. For example, a single 100-pair underground cable is considerably less costly to provide than two cables each of fifty pairs. Similarly, an amplifier station to cater for, say, 200 circuits is very much less costly to provide and maintain than two such stations each with 100 circuits. On the other hand, the provision of common circuit groups to serve a number of exchanges increases the number of switching points and thereby adds to the operating costs and increases the time necessary to set up calls. Automatic switching materially assists in this direction but, with any given method of working, the most economical degree of concentration is that which gives the minimum aggregate of operating and plant costs—consistent with a satisfactory time for the setting up of calls.

Zones. The arrangements adopted in practice divide the country into a number of comparatively large areas or *zones*. A suitable exchange located centrally (from a telephone traffic point of view) within each zone is chosen as the *zone centre* for the handling of long distance traffic to and from that zone. Great Britain and Northern Ireland are together divided into eighteen such zones as shown in Fig. 354 and a network of high-grade trunk circuits is provided between the zone centres to meet the traffic requirements. Ultimately, direct circuits will be provided between each zone centre and all other zone centres. At the present time, this network is not quite complete and in a few instances calls must be routed through an intermediate zone centre exchange.

It will be noted that the zone boundaries are determined more by the community of interest between the exchanges in the zone rather than the number of exchanges or telephones in the area concerned. The London zone, for example, is not greatly different in area from the Aberdeen zone but the London zone centre exchange handles very much more traffic than the zone centre at Aberdeen.

Groups. Each zone is in turn divided into a number of smaller areas or *groups* and one exchange known as a *group centre* is chosen as the switching point for the long distance traffic originated in or destined for that group. There are in all some 175 group centre exchanges in the country, of which some forty-four are in the London zone. Fig. 356 shows the location of the group centres in the Edinburgh zone. Other zones are similarly divided but, in densely telephoned parts, the area served by each group centre is considerably less than in the more sparsely telephoned areas. The group boundaries are determined by geographical considerations and by the community of interest between the exchanges. Similarly, the group centre exchange is

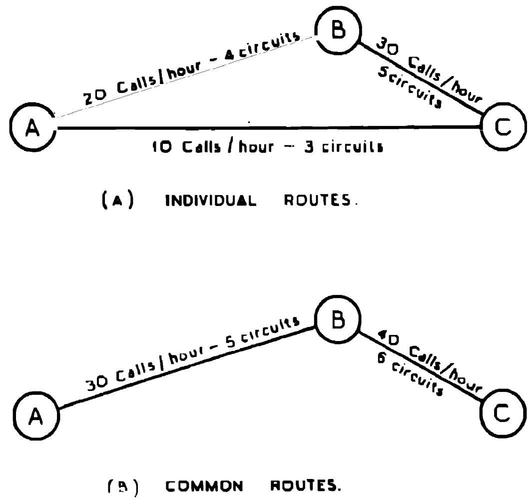


FIG. 353. ILLUSTRATING CIRCUIT ECONOMIES RESULTING FROM USE OF INTERMEDIATE SWITCHING POINT

located at the most convenient (and economical) centre for traffic within the group and to the zone centre. It should be noted that the zone centre exchange, in addition to handling traffic to and from the group centres within the zone, also acts as a group centre itself to serve a number of exchanges near the zone centre. Such exchanges would be classified as within the *zone centre group*. The Edinburgh zone is, therefore, divided into five group areas with centres at Edinburgh, Galashiels, Kirkcaldy, Perth, and Dundee.

Minor and Dependent Exchanges. Apart from group and zone centre exchanges which are equipped with special arrangements for the control, timing, and supervision of long distance calls, all other exchanges are known either as *minor exchanges* or as *dependent exchanges*. A minor exchange may be defined as one which has direct junctions to its group centre, whilst a dependent exchange is one which is not directly connected with its group centre but is dependent upon a minor exchange for long distance communication. To illustrate, in Fig. 356, Kelso, Jedburgh, Hawick, Selkirk,

Fountainhall, etc., are minor exchanges directly connected to the group centre at Galashiels. Yarrow, Ashkirk, etc., on the other hand, have no direct circuits to Galashiels and are therefore dependent exchanges on Selkirk. Stichill, Roxburgh, etc., are similarly dependent upon Kelso for obtaining access to the group centre.

Routing of Calls. Normally, each minor exchange acts as a switching point for traffic between its dependent exchanges, but passes forward to the group centre all traffic to points outside the minor exchange area. Similarly, the group centre deals with all traffic between the minor exchanges in the group, but routes through the zone centre all calls for exchanges in other groups. The zone centre in turn, acts as a switching point for all traffic to and from the zone. The normal routing of a long distance call is therefore from dependent exchange through the minor exchange, to the group centre, at which point the call is timed and controlled. The group centre extends the call to the zone centre where it is routed to the distant zone centre exchange. From this point, the call is extended to the appropriate group centre and thence to the minor and dependent exchange.

The above theoretical routing is, in practice, sometimes amended for calls where there is sufficient traffic to justify junction routes between

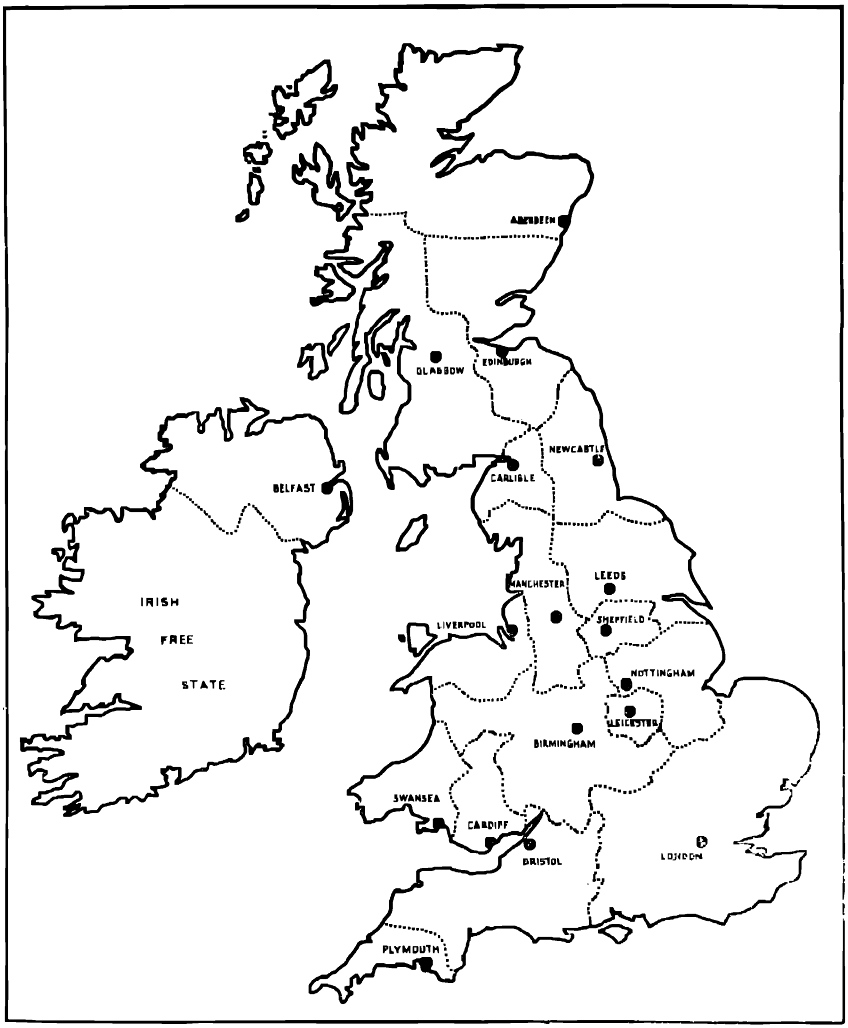


FIG. 354. DIVISION OF COUNTRY INTO ZONES

rby minor exchanges and group centres. It may happen, for instance, that there is sufficient ffic to warrant a route between two adjacent up centres (they may be in different zones). will be seen later, transmission requirements nit the use of such routes to calls within the two roup areas.

Classification of Traffic. In order to facilitate the design of external plant for trunks and junctions, a system of traffic classification is adopted. By so classifying the traffic it is possible to determine the types of calls which are to be passed over each individual junction or trunk route, and from this information the external plant is designed. Apart from calls between subscribers connected to the same exchange, telephone traffic is considered under one of the following three classes:

D Traffic comprises all calls between subscribers on exchanges which have direct communication with each other.

G Traffic comprises all calls (excluding D Traffic) between any two subscribers who are situated within the same group or are located in adjacent groups.

Z Traffic comprises all calls which are circulated through zone centre exchanges.

In addition to the above there is a further class of traffic (G2) for calls between subscribers situated within the same multi-exchange area. This traffic is really local traffic between subscribers on the several exchanges in a large city.

In the majority of cases each junction route is required to carry traffic of two or more of the above categories. For transmission purposes the plant must be designed to cater for the highest class of traffic. For example, if a particular junction route is required to carry G traffic and Z traffic, the line must be constructed to meet the Z traffic transmission standards. In large groups of junctions, however, it is sometimes possible to effect economies by segregating the junction group into two or more parts, each part being designed to carry one particular class of traffic only. In practice, combined traffic routes are usual when the number of circuits required is five or less, and segregation of traffic is adopted when the number of junctions exceeds this figure.

Trunks and Junctions. All inter-exchange circuits may be classified either as *trunks* or *junctions*. In this country a junction is arbitrarily defined as any circuit directly connecting two exchanges between the subscriber of which the charge is not more than four unit fees (4d.) at the full day rate. Similarly a trunk circuit is one for which the normal day charge is greater than four unit fees. Under present rates, the four unit fee provides service up to 15 miles radius from the originating exchange and hence any circuit in excess of 15 miles in length is referred to as a trunk line. Zone-zone circuits are invariably trunk lines, as also are the majority of zone-group circuits. Circuits within a group are generally in the category of junctions. It is important to appreciate that the terms "junction" and "trunk" have no reference to the method of working any particular group of circuits.

Circuit Efficiency. With modern telephone instruments, it is possible to introduce a maximum

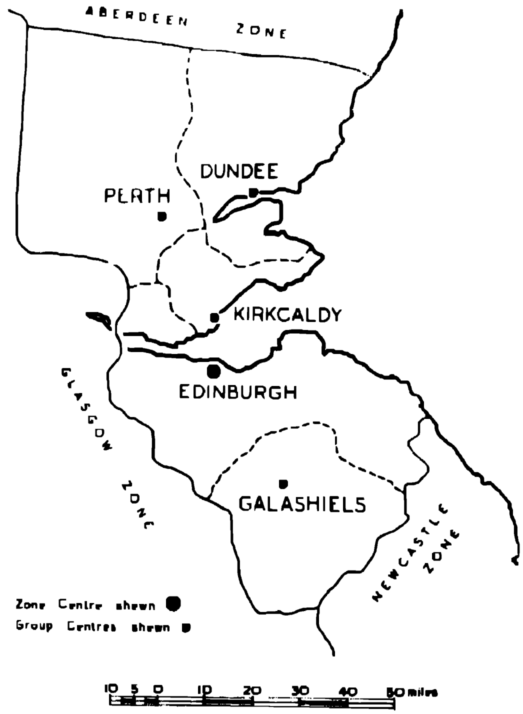


FIG. 355. SUBDIVISION OF A TYPICAL ZONE INTO "GROUPS"

transmission loss in the order of 30 db between calling and called subscribers. If the loss exceeds this figure, then the articulation and volume fall below commercial limits. There is a relation between telephone transmission efficiency and external plant costs. The cost of such plant increases rapidly as the permissible loss is reduced. There is, therefore, an economic balance between the transmission efficiency of a telephone system and its cost. The total permissible loss of 30 db is made up of a number of separate losses introduced by the various junctions, trunks, and exchange apparatus. It is extremely unlikely that any one

call will be routed over junctions and trunks all of which have the maximum transmission loss. The maximum possible loss in each link may therefore be fixed at a value which would result in a total

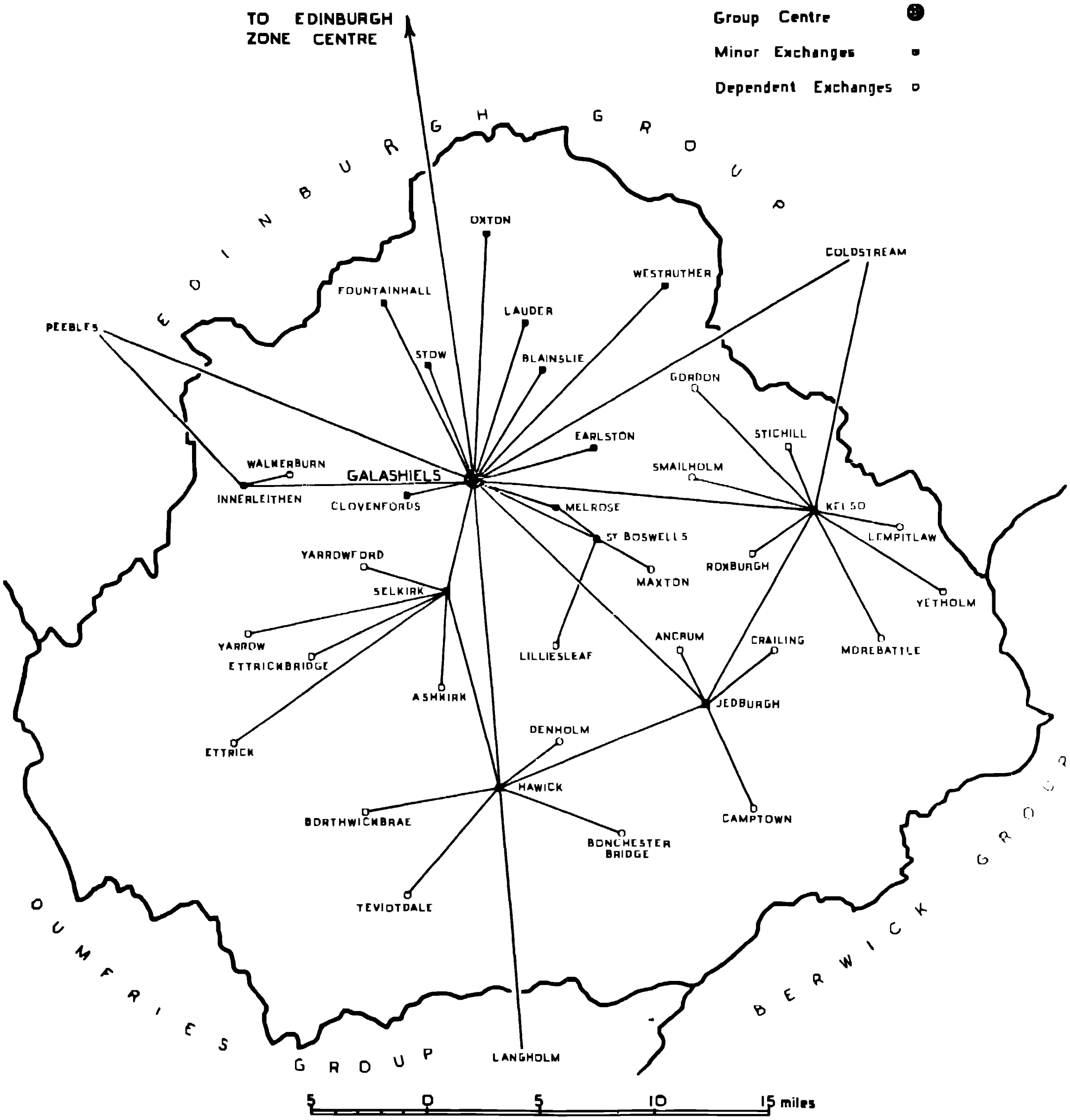


FIG. 356. NETWORK OF CIRCUITS IN A TYPICAL GROUP AREA

transmission loss somewhat greater than 30 db under the most adverse conditions. Thus it is possible to design the system with a total loss of, say, 33 db on the assumption that on any one call at least some of the links will be better than the lowest permissible standard. The subscriber's line to his local exchange introduces on an average loss in the order of 3 db. The transmission bridge at each switching point also introduces a further loss of approximately 1·5 db. On a long distance call from one dependent exchange to a similar dependent exchange in another zone, there are eight switching points. The total exchange and local line losses together are therefore approximately 18 db, leaving a residue of 15 db for the whole of the external lines between the two

rminal exchanges. This is the standard figure adopted in the British Isles for the maximum junction and trunk line loss on any call.

Traffic circuits may, for convenience, be considered under the three following categories:

(*a*) Zone centre to zone centre circuits.

(*b*) Zone centre to group centre circuits.

(*c*) Circuits radiating from group centres to minor and dependent exchanges.

To meet the standard transmission loss, amplifiers are required on all calls except those over the shorter links. It is more economical to concentrate the amplifiers on the zone-zone circuits and, to some extent, on the zone-group circuits rather than on the smaller and more numerous circuit groups radiating from group centres. It would be extremely uneconomical to provide high-grade circuits on the group to minor exchange links when quite a large proportion of the traffic on such junctions is of a local nature. Similarly, the group-to-zone circuits carry a high proportion of traffic which terminates within the zone. Zone-zone circuits, however, carry nothing but long distance traffic and should therefore be of the highest possible standard to allow the use of cheaper and less efficient circuits at the local ends.

The trunk and junction system in the British Isles is designed on the following basis:

Zone centre to zone centre circuits	0 db
Zone centre to group centre circuits	3 db
Group centre to minor exchange circuits	4·5 db
Exchange to exchange circuits carrying only terminal traffic	12 db
Junctions for local traffic in multi-exchange area	6·5 db

The zero loss zone centre to zone centre circuits are the main trunk backbone of the telephone service. The zero loss is, of course, obtained by the use of repeaters or amplifiers, and apart from the economical advantages of concentrating the losses in the more numerous local lines, the zero loss trunk circuits considerably facilitate the distribution of traffic due to the fact that calls can be set up through two or more zone centres for the same zero line loss. This enables alternative routing to be adopted with consequent savings in the total number of circuits to be provided.

The following table shows the transmission loss (db per mile) of various types of external lines. From the loss per mile, the maximum length of zone-group and group-minor circuits have been calculated. If the distances are greater than these figures, amplifiers must be inserted to reduce the loss to the standard limits of 3·0 db (group-zone) and 4·5 db (group-minor).

Composition of Line	Gauge of Condr. (lb/mile)	Loss per mile (db)	Maximum length (miles) of Zone to Group Circuits (3 db)	Maximum length (miles) of Group to Minor Circuits (4·5 db)
Overhead Line, Cadmium Copper	40	0·23	13	19·5
	70	0·16	18·7	28·1
Overhead Line, Copper	100	0·11	27·2	40·8
	150	0·08	37·5	56·3
Unloaded Underground Cable	6½	1·94	1·5	2·3
	10	1·56	1·9	2·9
	20	1·01	3·0	4·5
	40	0·70	4·3	6·4
Underground cable loaded 120 mH at 2000 yds	10	0·65	4·6	6·9
	20	0·33	9·0	13·6
	40	0·17	17·1	25·7

Junction and Trunk Network. Fig. 357 shows a hypothetical junction and trunk network. It illustrates two adjacent zones *X* and *Y*, each of which has three groups and each group centre has, in turn, three minor exchanges. Dependent exchanges are shown in some cases. A call from dependent exchange *D*2 in group *A* to dependent exchange *D*1 in group *F* would be routed via minor exchange *M*2, group centre *A*, zone centre *X*, zone centre *Y*, group centre *F*, minor exchange *M*3 to *D*1. It will be noted that where a minor exchange has dependent exchanges working to it, the total transmission loss from the dependent exchange to the group centre must not exceed the specified maximum figure of 4·5 db for circuits radiating from group centres. The total loss on this call is 15 db, of which 6 db is absorbed in the group-to-zone centre links and the remaining 9 db between the group centres and the dependent exchanges. All other calls routed in a similar manner have the same maximum loss.

Whilst the standard arrangement is to route all long distance calls via a group centre and then via the appropriate zone centre to the terminal group centre exchange, provision is made for direct circuits where the volume of traffic and the distance between the exchanges justifies such a course. Exchange *M*1 in group *B*, for example, is geographically close to exchange *M*3 in group *A*. If there is a sufficient community of interest between these two exchanges, a direct link is provided to avoid routing the call via the respective group centres. Such a junction route would only be used for calls from one minor exchange and its

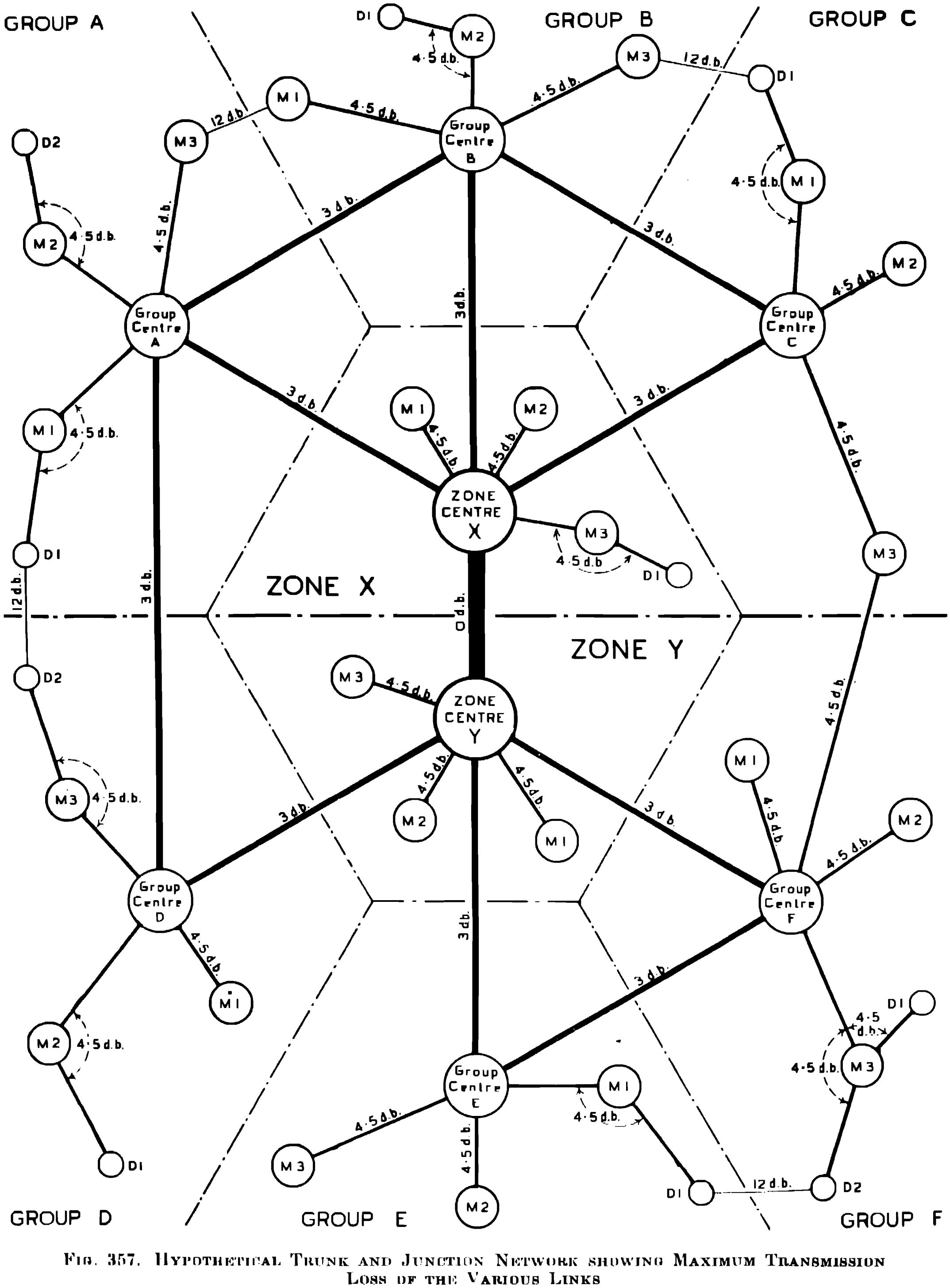


FIG. 357. HYPOTHETICAL TRUNK AND JUNCTION NETWORK SHOWING MAXIMUM TRANSMISSION LOSS OF THE VARIOUS LINKS

dependents to the second minor exchange area, and the system is so designed that irregular use of this direct circuit to obtain calls further afield is not permissible. Similarly a direct link circuit is shown between dependent exchange $D1$ in group C and the minor exchange $M3$ in group B. Conditions may so arise that a circuit between two dependent exchanges in separate but adjacent zones is warrantable—as between $D1$ (group A) and $D2$ (group D). A direct circuit in a rather different category is shown between minor exchange $M3$ in group C and group centre F. In this case it is assumed that there is a large community of interest between $M3$ and all the exchanges in group F, and hence a 4·5 db circuit is provided in order to keep the total loss within the figure of 15 db. It is possible in certain circumstances to route a call through three consecutive group centres and still keep within the transmission limits. For example, a call from $D2$ (group A) to $M2$ (group C) may be routed via group centres A, B, and C with a total transmission loss of 15 db. In some circumstances such a routing would be preferable to the more standard arrangement of passing the call through the zone centre. In Fig. 357 a direct circuit is shown between group A and group D although these two centres are in different zones. Such links may be and are provided where the volume of traffic and the geographical conditions justify such a course, but the traffic routed over the circuit should not extend beyond the limits of the two groups A and D.

Operating Methods. A long distance trunk route between, say, two remote zone centres may consist of several circuits only, whilst a short junction route between two large and busy exchanges may require several hundred circuits. The operating methods which may be quite efficient for small junction groups are not usually the most satisfactory arrangements for large groups of circuits. There are, moreover, many different types of junction route to cater for the traffic to and from manual and automatic exchanges with various switching and signalling systems. From time to time new methods of operating have been introduced, particularly in respect of large junction groups. In addition, mechanical aids have been applied wherever possible to improve the efficiency of the system. With the rapid expansion of automatic switching, it is probable that, in the near future, calls up to 15 miles radius will be completed automatically by the subscriber without the assistance of a telephonist. The longer distance and more costly calls will most probably still require an operator to set up and supervise the connexion. Even on such calls, the modern trend is to cut out, wherever possible, the intermediate and incoming operators and to provide more and more mechanical aids to the telephonist at the originating exchange. The following paragraphs describe the more common systems of operating junction and trunk routes.

Outgoing Circuits. At a manual exchange, all outgoing junctions must be accessible to every operator and the circuits must therefore be multipled throughout the switchboard. Because of the high volume of traffic on junction routes the outgoing junction multiple is invariably placed below the subscriber's multiple so as to be within easy reach of the operators. For the same reason it is also common practice to repeat the junction multiple at more frequent intervals than the subscriber's multiple. Means must be provided to advise the operator of the circuits in a junction group which are engaged at some other point on the multiple. When the junction group is small, say ten circuits or less, the standard "click" engaged test as used for subscribers' circuits is quite satisfactory. With larger junction groups the click test becomes cumbersome and slows up the operating procedure. Unfortunately at the busy time of the day when the operators are most heavily loaded a large number of the junctions are engaged. Hence the time required to find a free circuit is greatest at the periods when the operator can least spare the time. It is nowadays usual to provide some form of group tests or visual indication to facilitate the selection of a circuit in a large junction group.

Group Engaged Tone. A system known as the *Group Engaged Tone* (G.E.T.) which is designed to speed up the testing of outgoing junctions, is shown in Fig. 358. The outgoing junctions on a particular route are divided into groups of five. A sleeve relay is provided per junction and, if all junctions in one group are engaged, the contacts of their associated sleeve relays apply a continuous 400 c/s tone to the bush of the first junction in the group. Thus if an operator receives the Group Engaged Tone on the first junction, she knows that the four subsequent junctions are engaged and proceeds to test the sixth junction. Similarly, if the sixth junction, being the first of the second group of five, gives the Group Engaged Tone, she proceeds to test the eleventh junction and so on. Whilst Group Engaged Tone is not so effective as the various visual methods, it has, nevertheless, the merit that no additional switchboard space is required for the accommodation of lamps and it is therefore very suitable for adding to existing outgoing multiple jacks.

Visual Engaged Signal. *Visual Engaged Signals* (V.E.S.) require the provision of one lamp per outgoing junction which is arranged to glow if that junction is engaged. The lamps are fitted with

distinctive green caps and are lighted from local contacts of the junction sleeve relay as shown in Fig. 359. Visual engaged signals enable an operator to see at a glance the engaged lines in any outgoing junction group, and although it is not necessary to provide the normal click test, it is the usual practice to retain this facility for use in the event of failure of the visual engaged signals. Visual engaged signals are satisfactory when the switchboard is not congested and where the number of junction groups is not large. At large and busy exchanges, however, the current consumption becomes extremely high and there is difficulty in arranging for the dissipation of the heat produced. Moreover, the signals are "negative" in that the operator must search for a junction where the engaged lamp is *not* glowing.

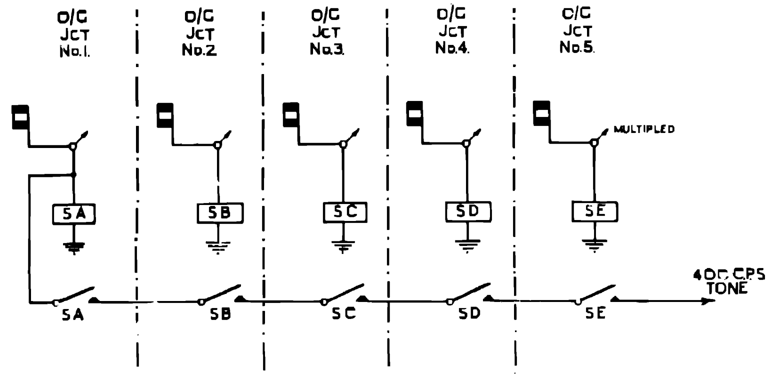


FIG. 358. PRINCIPLE OF GROUP-ENGAGED TONE

Free Line Signals. Modern exchange practice favours a system in which the first free circuit in a group is indicated by a visual signal. *Free Line Signals* (F.L.S.) as they are called, give a positive indication to the operator of the next circuit she must use. The current consumption is always limited to that of one lamp per junction group, irrespective of the size of the group and the number of circuits engaged. Further economy of power is obtained by the use of 6 V low consumption lamps. If all circuits are free, the lamp associated with junction No. 1 glows from the earth via contact *SA* normal (Fig. 360). When this first circuit is taken into use, *SA* operates and the earth is extended to the lamp of junction No. 2. In this manner the free line signal passes on to the next free junction as each circuit is taken into use.

In order to economize in switchboard space, the normal lamp caps are replaced by a label-holder which has a small hole to allow a pin-point of light to show when the lamp is glowing. By this means a separate designation strip is avoided and the free line signal lamp is more closely associated with the description of the circuit (see Chapter XIX).

With the advent of a reliable a.c. mains supply, some savings can be made in the size of batteries by the use of alternating current for the lighting of free line signals. In the practical arrangement the mains voltage is transformed down to about 6 V and provision is made to cut off the supply during quiet periods in order to economize in power consumption.

Incoming Jack-ended Junctions. The termination of an incoming circuit on a jack and calling lamp, similar to the arrangement for subscribers' lines, is perhaps the most straightforward method. Junctions worked on this basis are referred to as *Incoming Jack-ended Junctions* or more frequently just *Jack-ended Junctions* (Fig. 361). In some respects it is desirable that jack-ended junctions should be distributed amongst the available operators' positions so that an even loading of the operators is obtained. In practice, the peak traffic at different exchanges often occurs at different times even although the several exchanges may be geographically near together. If, therefore, incom-

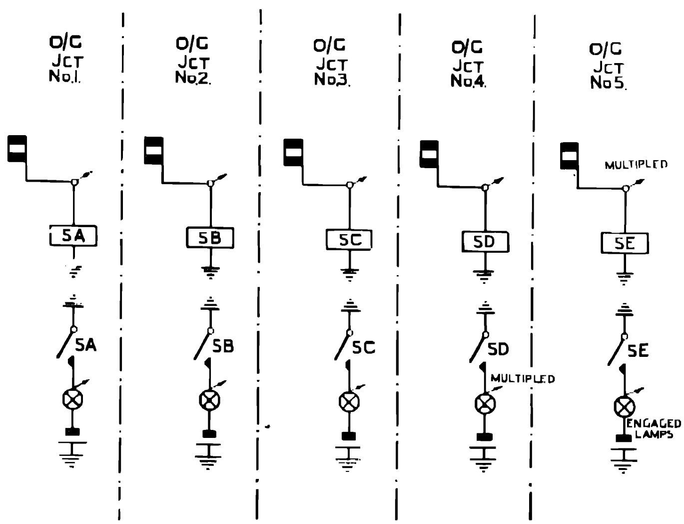


FIG. 359. PRINCIPLE OF VISUAL ENGAGED SIGNALS

ing junctions are concentrated on one or two positions, it is possible that these positions will be heavily worked at a time when the other positions handling local subscribers' traffic only are comparatively quiet. Similarly when the local originating traffic is at its peak, it is possible that the traffic received over the incoming junction routes may be considerably below the maximum value. By distributing the incoming junctions over all positions the full operating staff is available to meet the consecutive peaks of local and junction traffic.

In small exchanges of several positions there is insufficient incoming traffic to warrant the continuous attention of one operator, and in these circumstances there is no alternative to distributing the junctions over the ordinary subscribers' positions. In larger manual exchanges, however, there is generally sufficient incoming junction traffic to occupy several operators and, if necessary, it is practicable to concentrate the incoming junctions onto one or more positions. In certain manual exchanges, and particularly in the C.B. system to be considered later, special facilities are required on the cord circuits used for answering junction calls. If, therefore, the junction traffic is to be distributed amongst all the available positions it is necessary to provide a few special cord circuits on all positions for use on incoming junction calls. For this and other reasons, it is usual at manual exchanges to provide special positions for the handling of incoming junction traffic when the amount of such traffic is sufficient to load at least one operator. These positions are designated *B-Positions* in order to differentiate from the *A-Positions* which are provided primarily to deal with calls from local subscribers. A B-position equipped with jack-ended incoming circuits is therefore known as a *Jack-ended B-Position*.

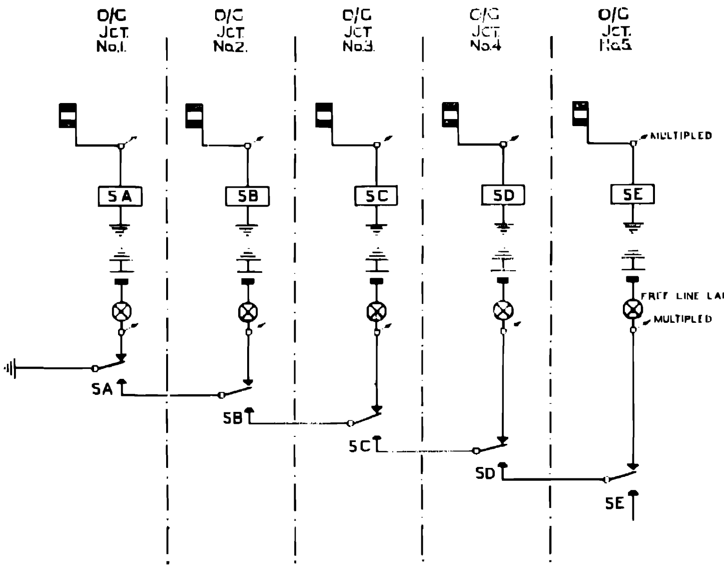


FIG. 360. PRINCIPLE OF FREE LINE SIGNALS

Bothway Jack-end Junctions. Although jack-ended working provides a convenient method of terminating small groups of junctions, it is not the most efficient method if the number of junctions is large and the traffic is heavy. With a jack-ended circuit of any type the operator has firstly to insert the answering plug of a cord circuit into the incoming jack, secondly to throw the speak key, and finally to insert the calling plug of the cord circuit into the required line and to ring the latter. These operations can be reduced by terminating incoming circuits on special plugs so that the operator has merely to pick up the plug of the calling junction and to insert it into the required line. Jack-ended junctions are therefore mainly used for small groups of five or less circuits. With such small groups it is uneconomical to adopt unidirectional working, and it is usual for jack-ended junctions to be arranged for *bothway working*, i.e. to carry traffic in either direction. A block schematic of a bothway jack-ended junction is shown in Fig. 362. Ordinarily the junction is switched to the incoming equipment

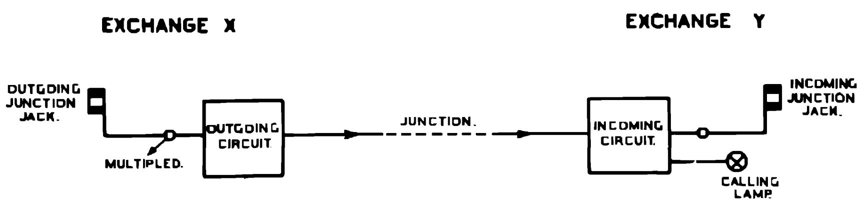


FIG. 361. JACK-ENDED UNIDIRECTIONAL JUNCTION

at both terminal exchanges. If a plug is inserted in the outgoing jack at, say exchange X, the circuit is arranged to change over contact $X1$ so as to cut off the incoming equipment and to connect the outgoing jack to the junction proper. It is preferable to effect the switching from the incoming side to the outgoing side at the originating exchange, since the switching operation is more easily controlled at this end of the circuit than at the distant end.

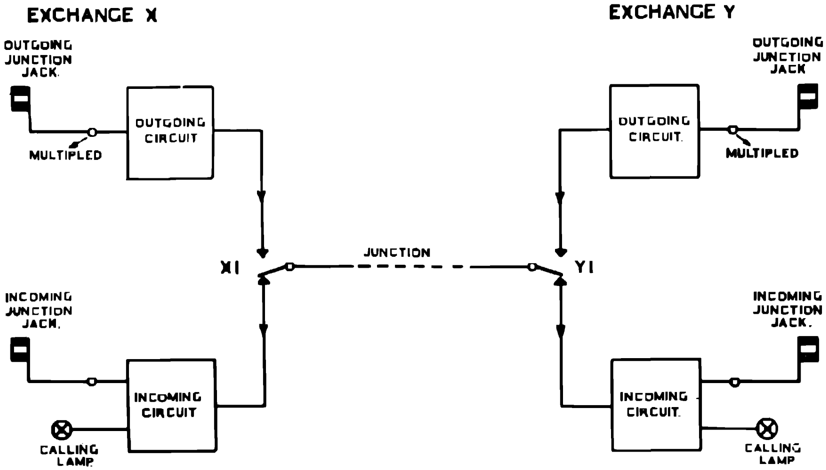


FIG. 362. BOTHWAY JACK-ENDED JUNCTION

Plug-ended Junctions. The arrangements of a plug-ended junction circuit are shown in Fig. 363. The outgoing end of the circuit is identical with that of the jack-ended circuit already considered and may be provided with any of the aids to facilitate testing. At the incoming exchange (Y) the circuit is terminated on a single-ended plug, and a cord circuit is provided to receive the necessary calling and supervisory signals. A speak key per junction enables the operator to answer an incoming call, and after she has received instructions, the junction plug is inserted into the required line. In the later circuits of this type, equipment is provided in the cord circuit for ringing automatically the called subscriber, but in some of the earlier circuits, a ringing key combined with the speaking key was used. The simplicity of the operating procedure and the fact that only one plug per junction is required, enables a large number of incoming junctions to be terminated on one position. There is, however, one disadvantage of plug-ended junction working in that it is not possible to adopt team working between an operator on a plug-ended B-position and the operator on an adjacent jack-ended B-position or subscriber's A-position.

Order-wire Junctions. If it is possible to arrange that the outgoing operator has no necessity to test the outgoing circuits to find a free junction, and for both the outgoing and incoming operators to establish the connexion *concurrently* instead of *consecutively*, then some increase in efficiency can be obtained. These two aims are realized in *plug-ended order-wire junction* working, which is illustrated in Fig. 364. For each junction route between two exchanges, a special circuit is provided and is known as an *order-wire*. The operator at Exchange X, on receiving a request for a call to Exchange Y, depresses a plunger type key on her position which places her telephone in direct communication with the incoming operator at Exchange Y over the order-wire. Exchange X requests the number required at Exchange Y, and the latter operator calls back to the originating operator the number of the free junction to be used. Both operators then complete the connexion simultaneously, the outgoing operator plugging into the junction assigned by the incoming operator, and the latter placing the incoming plug of the same junction into the multiple jack of the required line (after, of course, testing for the engaged condition). It is arranged that the tips of all disengaged incoming junction plugs are connected to the operator's telephone circuit so that the incoming operator can test a

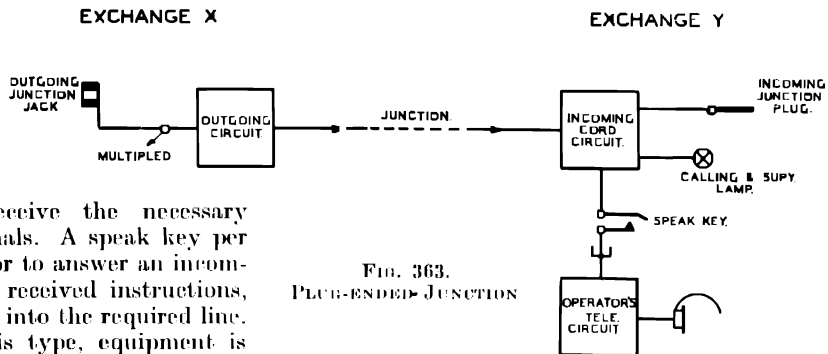


FIG. 363. PLUG-ENDED JUNCTION

line with any of the plugs without having to throw a key to associate her telephone with that plug. After testing and when the plug is fully inserted, contact S removes the tip circuit from the operator's telephone and connects it through to the junction. To speed up operating procedure still further, it is usual to arrange the cord circuit of the incoming junction to ring the called subscriber automatically and to cut off the ringing when the subscriber replies.

Plug-ended order-wire junction working has completely superseded plug-ended signal junctions and has proved to be highly satisfactory, especially on very large groups of junctions. There are, however, certain limitations:

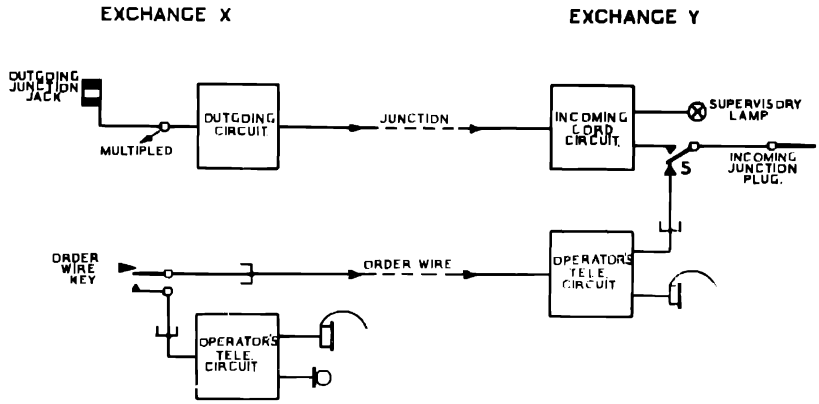


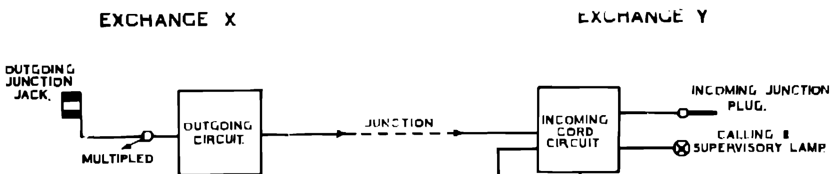
Fig. 364. Plug-ended Order-wire Junction

(*a*) The method is unsuitable for small groups of junctions owing to the cost of the order-wire itself.

(*b*) A large number of junctions is required to provide a load for one incoming operator. If this is not possible, several order-wires from different exchanges are linked together to one operator and the arrangement is then known as a *split order-wire*. On split order-wires it is, incidentally, necessary for the originating exchange to advise the incoming operator of the name of the calling exchange so that a junction in the correct group can be assigned.

(*c*) There is always the danger, especially with split order-wires, of errors due to interruptions of a request by other operators and due to phonetic errors.

(*d*) The system does not lend itself to team working or for the concentration of traffic during slack periods. It may, for example, so happen that at a given time, one group of junctions carries very little traffic whereas a group from another exchange may be very busy. Even although the two junction groups may be terminated on adjacent positions, it is difficult to arrange for both operators to share the load. Similarly, if order-wires are coupled together during the slack periods, the resultant operating is not very convenient owing to the long reaches involved.



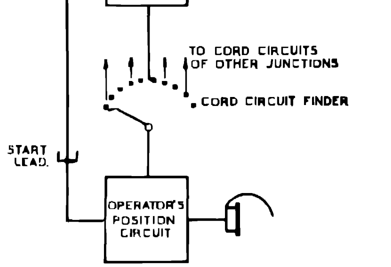


Fig. 365. Straightforward Junction Working

Straightforward Junction Working. Straightforward junction working (S.F.J.) was introduced some years ago to obviate the limitations of order-wire working and is illustrated in Fig. 365. The operator at the originating exchange tests for, and plugs into, a free outgoing junction; group engaged tone or free line signals being provided to facilitate the selection of a free line. The insertion of a plug into the outgoing jack causes an automatic selector of the rotary type (the cord circuit finder) to hunt for and seize the calling junction, thereby associating the incoming operator's telephone with the line. Two pips of 900 c/s tone are then returned to the calling operator to indicate that the incoming operator is listening. The calling operator passes over her demand and the incoming operator, who knows the junction to which she is connected by the flashing of the supervisory lamp, completes the connexion as in order-wire working. As soon as the plug is inserted into the required line, the cord circuit finder switch and the incoming operator's circuit are disconnected from the junction and are ready to search for the next call.

The absence of an order-wire makes it possible to mix on one position groups of junctions from a number of exchanges. Moreover, a number of small groups of two or three junctions can be worked economically on a straightforward junction basis, and traffic can be levelled out between operators by arranging that each operator has junctions from *all* the incoming routes to that exchange. If, for example, there are nine groups of sixteen circuits, each terminated at a given exchange and these circuits require the services of four operators, a fairly even distribution of traffic is obtained by giving each operator four circuits from each of the nine groups. As in ordinary plug-ended junction working, the junctions are tied to a given cord circuit and simple S.F.J. working does not therefore lend itself to efficient concentration during slack periods. It is, in fact, more difficult to couple together the finder equipment of S.F.J. positions than to couple order-wires. Some improvement on order-wire working can be obtained by so distributing the incoming junctions that the first choices of each group are terminated on one position which is always staffed during slack periods, but this course does, to some extent, upset the normal distribution of traffic.

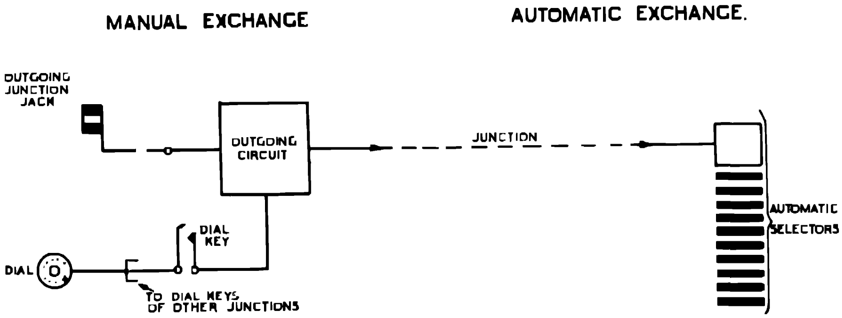


Fig. 366. Outgoing Dialling Junction with Dial Key per Junction

In large exchanges where a uniform distribution of traffic and an efficient means of concentration are essential, a development of S.F.J. working has been devised to give automatic distribution of traffic to the available operators, irrespective of the number of positions staffed. The detailed arrangements are described in Chapter XVII. In principle, all incoming junctions are terminated on the banks of a series of linefinder switches, one of which is provided per cord circuit. On receipt of an incoming call, a distributor determines which cord circuit is next to be used, and causes the linefinder of this circuit to hunt for the calling junction. Cord circuits located on unstaffed positions are automatically busied at the distributor and the calls are offered to the available telephonists in strict rotation.

Direct Dialling to Automatic Exchanges. As the number of automatic exchanges increases, the problem of communication from the remaining manual exchanges to the automatic network becomes of increasing importance. If the volume of manual-automatic traffic is not excessive, arrangements can be made for the manual exchange operator to dial any required number on an adjacent automatic exchange in exactly the same way as a subscriber in an automatic area obtains local numbers. For obvious reasons, it is not practicable to provide a dial on every outgoing circuit at a manual exchange, and in practice one dial per operator's position is provided together with facilities for connecting that dial to any outgoing junction as required. It is apparent that means must also be provided to hold the connexion to the automatic exchange after dialling when the dial loop must be dissociated from the junction.

At magneto and C.B.S. exchanges equipment is provided in the outgoing junction circuit to change from the cord circuit signalling conditions to the signalling arrangements required over the junction itself. In all such exchanges, therefore, it is necessary to provide a means of access to the junction on the line side of this outgoing signalling equipment. In very small exchanges, where the number of outgoing junctions to automatic exchanges are few, a *dial key* per outgoing junction is provided. On receipt of a call for the automatic exchange, the operator throws the dial key (Fig. 366) associated with the first free junction and then proceeds to dial in the normal way. At the end of dialling the dial key is restored and correct conditions for conversation are established. When, on the other hand, the number of outgoing circuits to distant automatic exchanges becomes greater, the panel space required for the dial keys makes this scheme impracticable. It is usual in such circumstances to terminate the position dial on a special *dialling plug* (usually at the right-hand end of the plugshelf). Two jacks are provided for each outgoing circuit, one being the normal outgoing jack into which the calling plug is inserted and the other a dialling jack into which the operator places the dialling plug (Fig. 367). At the end of dialling,

removal of the dialling plug automatically restores the conditions for speaking and for holding the distant automatic exchange equipment.

At C.B. exchanges it is not usual to have signalling equipment associated with the outgoing junction jacks. It is therefore possible to associate the position dial with the particular cord circuit in use. The usual arrangements are as shown in Fig. 368. A *dial switching key* is provided at the right-hand side of the position and by its operation the ringing supply leads to the cord circuits are switched over to the dial impulse springs. Hence it is possible for the operator to connect the dial to any calling cord by holding the appropriate ringing key in the operated position and by throwing the dial switching key. At the end of dialling, the ringing key is released and holding conditions are supplied from the cord circuit. There is some danger with this scheme of the operator forgetting that the ringing supply to the position is cut off at the dial switching key. To minimize this danger a dial guard lamp is provided to warn the operator whenever the dial switching key is thrown.

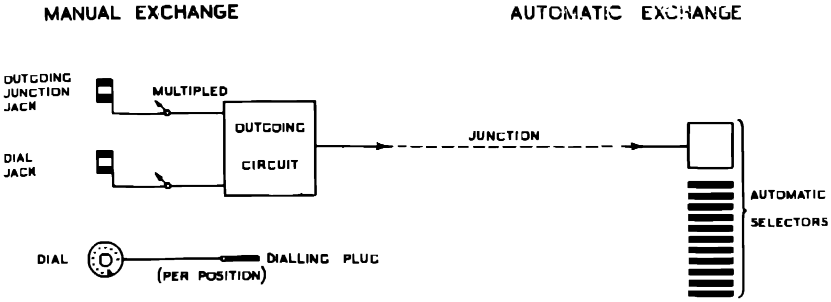


FIG. 367. OUTGOING JUNCTION WITH DIALLING JACK

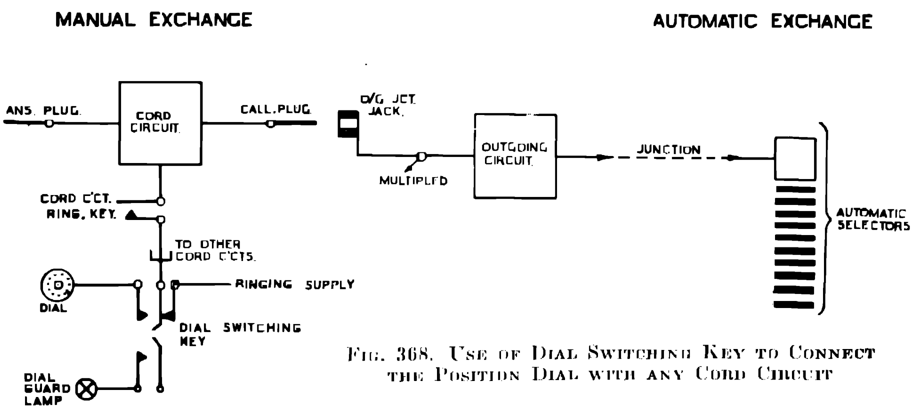


FIG. 368. USE OF DIAL SWITCHING KEY TO CONNECT THE POSITION DIAL WITH ANY CORD CIRCUIT

Keysending. Where a large percentage of the originated traffic at a manual exchange is to subscribers on nearby automatic exchanges, the process of dialling becomes cumbersome, and a more efficient method of setting up calls is desirable. The onus of dialling can of course be transferred to the operator at the automanual exchange serving the automatic subscribers, the junctions between the manual and the automanual exchanges being worked on a jack-ended or a plug-ended basis. Even so, a large number of incoming operators are required at the automanual exchange on account of the comparatively long time required to set up each call by dialling. To reduce this time and hence to increase the traffic capacity of each operator, a rapid method of setting up connexions known as *keysending* is adopted. In the early forms of keysending, junctions were provided on an order-wire basis between the manual exchange and the automanual switchboard, the incoming junctions being terminated at the latter on specially designed positions. The incoming positions are of a cordless type with a plunger type key and a supervisory lamp per junction. A special strip of ten press-button keys known as a *digit key strip* is provided per position, the press buttons being designated by the numerals 1, 2, 3, . . . 9, 0.

On receipt of a request over the order-wire, the incoming operator calls back the number of the junction to be used and, by depressing the plunger key corresponding to that junction, causes a special piece of automatic equipment called a *sender* to be associated with both the junction and the position digit key strip. The incoming operator "keys-up" the number required by depressing in rapid succession the digit keys proper to the number. If, for

example, subscriber No. 2345 is required, the operator depresses digit keys 2, 3, 4, and 5 in sequence. The depression of a digit key sends a combination of signals to mark the banks of a switch in the sender. On completion of keying, the sender translates the signals from the key strip into corresponding break impulses which are directed to step the automatic selectors as required. As soon as an operator has finished keying up a number, her position is automatically freed for the setting up of other calls whilst the sender proceeds to supply the impulse trains to the automatic selectors. At the end of impulsing the sender and the other common

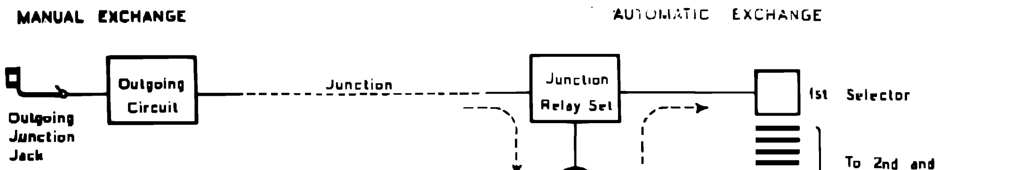
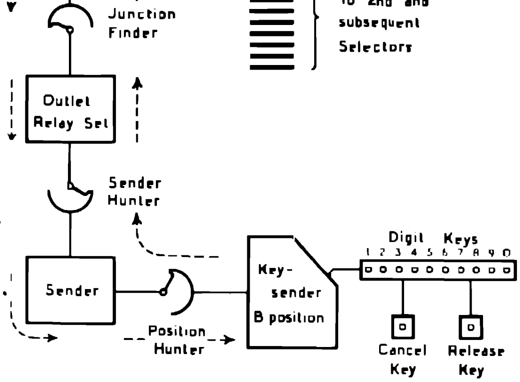


FIG. 369. S.F.J. KEYSENDER WORKING



apparatus are released for the setting up of further calls. By these arrangements the operating time for establishing a connexion is appreciably under one second, as compared with, say, four seconds which is an average time for dialling a four-digit number.

S.F.J. Keysender Working. The merits of straightforward junction working for communication between two manual exchanges also apply when the calls are destined for automatic subscribers. Order-wire keysender working has therefore been superseded by a variation employing S.F.J. principles. The general trunking arrangements of S.F.J. keysender working are illustrated in Fig. 369. When a call is required for a subscriber on the adjacent automatic exchange, the A-operator at the manual exchange tests for a free junction and plugs into the outgoing junction multiple in the usual way. At the automatic exchange the incoming junctions are terminated on junction relay sets which are wired to the banks of a number of uniselectors known as *junction-finders*. Associated with each junction finder is another uniselector known as a *sender-hunter*, and each pair of uniselectors with the associated relays are controlled by an outlet relay set. Whilst the junction finder is searching for the calling line the associated sender-hunter also hunts for a free sender. The senders form a common group for the whole automatic exchange, and associated with each sender is a position-hunter uniselector, the banks of which give access to keysender B-positions. When a B-position is found, a two-pip signal of 900 c/s tone is returned to the originating A-operator and the calling cord supervisory lamp is darkened as an indication to the operator that she may proceed with the call. The A-operator now gives the number required to the B-operator who sets up the call by the consecutive depression of digit keys. When the last digit key has been depressed, the incoming position is freed ready to receive further calls, whilst the sender mechanism starts to send normal break impulses to the automatic selectors. When all the digits have been transmitted by the sender the calling junction is switched through and the outlet, sender and the associated apparatus are released.

Facilities are provided to enable the B-operator to cancel any incorrectly set-up call by the operation of a Cancel key on the position. Similarly if the position is seized by a distant operator but no number is demanded, the B-position operator can release her position by the operation of a second key known as the Release key.

Voice-frequency Keysending. Still further progress towards increased efficiency can be made if facilities are provided for the originating exchange operator to key-up the number herself instead of requesting the incoming operator at the automatic exchange to do this for her. The problem is in effect to modify the signalling circuits between the digit key strip and the sender to enable the signals to be sent over a junction. In keysender B-position working four or five wires are required between the digit keys and the sender for signalling purposes. One scheme of keysending from A-positions is to extend these wires as a form of order-wire to the distant exchange and to adopt d.c. signalling

methods over the four conductors. This *mechanical order-wire* arrangement has now been replaced by a system of voice-frequency keysending in which all signals are passed along the two speech conductors by the use of voice-frequency currents. In start key—provided that the last digit has not been sent out. If the error is discovered after the last digit key has been depressed, the calling plug must be withdrawn from the jack and the call re-established.

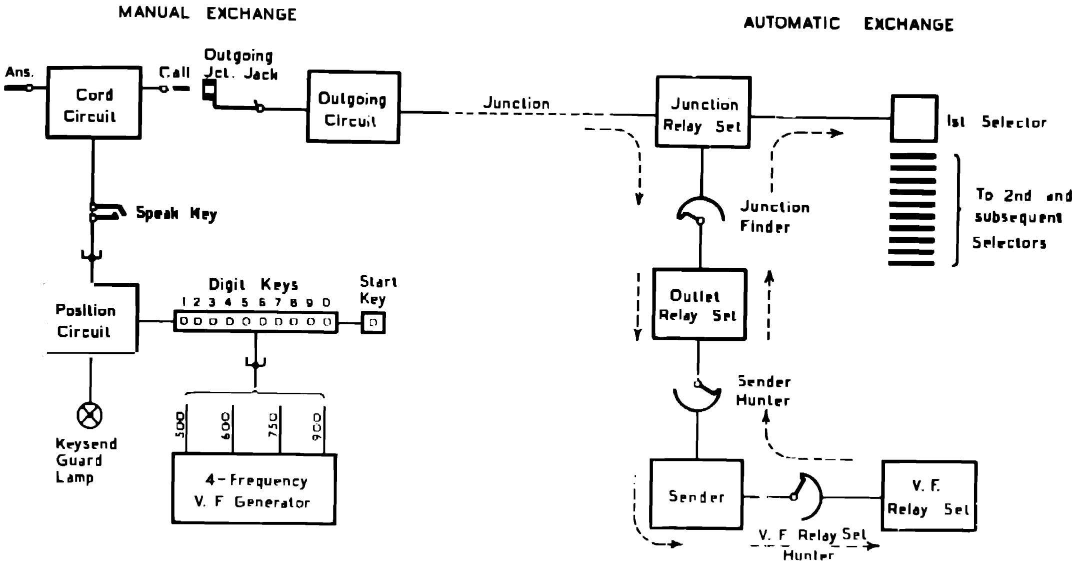


FIG. 370. VOICE-FREQUENCY KEYSENDING FROM A-POSITIONS

voice-frequency keysending, a digit key strip is provided on all subscribers' positions at the originating exchange. This key strip can be associated with any calling plug on the position by the operation of the appropriate speak key. The arrangements at the automatic exchange are substantially as for keysender B-position working except that the position hunter is now replaced by a voice-frequency relay set hunter, the banks of which give access to voice-frequency relay sets (Fig. 370). When a free voice-frequency relay set is found, a two-pip signal is returned to the A-operator and, as before, the calling cord supervisory lamp at the manual exchange is darkened. The A-operator now depresses the start key in order to cancel any false operation of the voice-frequency receiving relays which may have occurred due to speech or line noise. The operator then proceeds to key-up the call, and when the last digit has been depressed the voice-frequency relay set is released to receive further calls and the sender commences to send out break impulses to step the automatic selectors. When all the digits have been transmitted, the junction is switched through to the selector, and the outlet, sender, etc., are released. If the A-operator erroneously depresses a wrong digit key she can cancel the call by depressing the

2 V.F. Signalling and Dialling. In recent years a voice-frequency signalling scheme has been developed to permit of automatic signalling or dialling over long trunk circuits. Voice-frequency currents of two frequencies (hence 2 V.F.) are used for signalling and the system provides automatic calling and supervision on circuits which, for technical reasons, did not previously give these facilities.

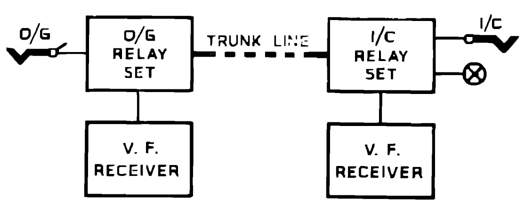


FIG. 371. GENERAL ARRANGEMENTS OF 2 V.F. SIGNALLING CIRCUIT

The general arrangements of a voice-frequency signalling circuit between two manual exchanges are illustrated in Fig. 371. The d.c. calling signal from the cord circuit at the originating exchange is converted in the outgoing relay set to an a.c signal of voice frequency which in passing along the trunk line is amplified in the same way as normal speech. At the incoming end of the circuit

the voice-frequency signal is converted in the V.F. receiver to a d.c. signal to operate the calling lamp. Supervisory and flashing signals are similarly transmitted as V.F. signals along the line, and the V.F. receivers convert the a.c. signals to the appropriate d.c. conditions. It is interesting to note that on 2 V.F. signalling circuits an extended engaged test facility is provided to maintain the engaged condition on the outgoing multiple until such time as the plug is removed from the incoming jack.

2 V.F. signalling between distant trunk switchboards has now been replaced by a system in which

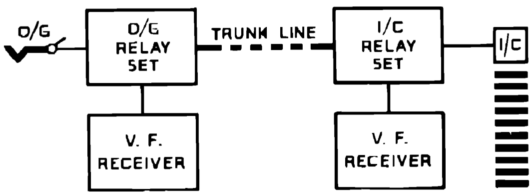


Fig. 372. General Arrangements of 2 V.F. Dialling Circuit

the originating trunk operator dials direct into the automatic network of the terminal trunk exchange (Fig. 372). Direct automatic access is at present limited (for technical reasons) to the subscribers in the locality of the incoming zone centre. All other calls are obtained by dialling "0," which extends the call to an operator at the incoming trunk switchboard. Arrangements are in hand, however, to extend the 2 V.F. dialling scheme so that a trunk operator will ultimately be able to dial any automatic subscriber in the British Isles. It is apparent that the 2 V.F. dialling scheme enables a very considerable reduction to be made in the number of incoming trunk operators.

Automatic-to-Manual Exchange Traffic. Calls from an automatic area to a nearby manual exchange may be completed over direct dialling circuits from the selector levels at the automatic exchange. Such circuits are usually terminated on ordinary jack-ended answering equipment at the manual exchange. For traffic reasons, direct dialling to a manual exchange by automatic subscribers is usually restricted to those manual exchanges which are within the automatic metering radius of the originating exchange. If, for any reason, direct dialling by the subscriber cannot be provided, then the calls must be routed via the automanual operator and thence on ordinary manual to manual junction circuits. In these cases the automanual operator controls and tickets the call.

No further comment is needed in respect of calls routed via the automanual operator, but direct dialling circuits introduce several interesting problems. Automatic switches release within a fraction of a second of the calling subscriber replacing his receiver, but the incoming operator at a distant manual exchange takes a considerably longer time to take down the connexion. There is, therefore, the danger of a second call being routed over the same junction to the manual exchange before the incoming operator has cleared down the first connexion. To avoid confusion and unnecessary disturbance to subscribers, facilities are nowadays invariably provided for a follow-on call to be received at the manual exchange if a previous connexion has not been removed. These circuits are arranged to relight the calling lamp on receipt of the second call and to prevent disturbing the called party of the first call. As an alternative to this arrangement, it is sometimes possible to maintain the engaged condition on the outgoing junctions at the automatic exchange for so long as an answering plug is held in the incoming jack at the manual exchange.

The second important difficulty on automatic-to-manual circuits is in connexion with metering and supervisory facilities. Great care must be taken in the design of the cord and incoming line circuits to prevent false registration when the operator answers and before the called subscriber replies. Generally speaking, the supervisory condition returned by an incoming operator on manual-to-manual circuits is substantially similar to the metering condition on automatic to manual circuits. It is difficult, therefore, sometimes to maintain full supervisory conditions on manual routes and at the same time to avoid false metering on calls originated by an automatic subscriber.

Automatic-to-Manual Exchange Traffic in Large Cities. A large and densely telephoned city such as London contains a number of telephone exchanges in close proximity with a high community of interest between the exchanges. The conversion of such an area to automatic working presents a number of problems during the transition period, especially in respect of calls from automatic to manual exchanges within the area. The routing of all calls to manual exchanges via the automanual switchboards is generally impracticable on account of the very large volume of such traffic, especially during the early stages of conversion. The alternative of adopting dialling codes by means of which the automatic subscribers would obtain direct access to the various manual exchanges has also a number of objections. As will be seen later, the automatic system in a large city is of the Director type in which automatic subscribers dial the first three letters of the exchange name followed

by the four numerical digits of the required subscriber's number. The adoption of a numerical dialling code of two or more digits (as is done in non-director areas) would necessitate a change in the instructions to every subscriber within the area each time a manual exchange in the area is converted to automatic working. Some improvement could be made by arranging that the dialling code should be the first three letters of the manual exchange name. Even if letter dialling codes could be introduced the subscriber would be required to differentiate between calls to automatic exchanges in which he would follow the code by a four-figure number, and calls to manual exchanges where the letter code only would be dialled. Possibly the greatest complexity is, however, the very frequent changes of directory entries which would be necessary as each manual exchange is converted to automatic working. A uniform system of dialling could be attained if automatic subscribers were instructed to dial the three initial letters followed by the four numerical digits for every number irrespective of whether the required exchange were automatic or manual. On manual calls the first three letters of the exchange name could be used to route the call to the required exchange but the numerical portion would, in the absence of automatic switching equipment at the manual exchange, be of no use in establishing the call. It is not considered reasonable to expect a subscriber to dial seven digits and then to be asked the number required by the manual exchange operator.

In the London, Manchester, and Birmingham areas, special equipment has been installed to give a visual indication to the incoming manual exchange operator of the number required. In these areas all automatic subscribers dial the three initial letters of the exchange name followed by the four numerical digits on all calls. The letter digits are used to route the call through the automatic switches to the required manual exchange, and the numerical digits light a display panel in front of the incoming operator at the manual exchange. This system of handling automatic to manual exchange calls is known as the *Call Indicator System*. In the British scheme the signals from the automatic to the manual exchange are changed from break impulses to special coded pulses of heavy and light current along the junction wires. This scheme is therefore known as Coded Call Indicator working (C.C.I.). At the manual exchange the standard incoming plug-ended B-positions have been adapted by the addition of a display panel on each position keyshelf. This display panel (Fig. 373) consists of four groups, each of ten lamps, behind a stencilled and ground-glass screen. The coded signals received from the automatic exchange are made to light one lamp in each group and thereby to give a visual indication of the number required. A duplicate display panel normally

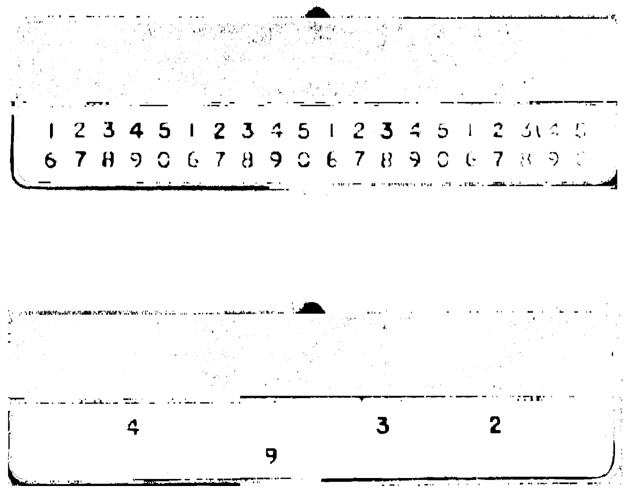


FIG. 373. CALL-INDICATOR DISPLAY PANEL

concealed by a metal cover is provided so that the position will not be put out of service due to the failure of a display lamp.

C.C.I. equipment has not been provided at Liverpool, Glasgow, or at other large cities at present in the process of conversion to automatic working. Apart from London, which has some hundreds of exchanges, the remaining cities of the British Isles contain not more than a few dozen exchanges, and the expense of C.C.I. equipment is avoided by arranging for the exchanges to be transferred to automatic working in three or four stages. Directory changes are reduced to a minimum by arranging to change over the exchanges in groups, and it is found practicable to handle automatic-to-manual exchange traffic during the transition period through the automanual switchboard or by the use of dialling codes consisting of the first three letters of the exchange names.

C.C.I. System. Fig. 374 shows the general arrangements of coded call indicator working between an automatic and a manual exchange. The outgoing junctions to the manual exchange

are connected to the levels of group or code selectors at the originating automatic exchange. When a junction is seized from the selector level, the call is automatically extended via a C.C.I. relay set to a uniselector (coder hunter) which hunts for and seizes a free coder. The break impulses of the required subscriber's number are passed into the coder where they are stored in readiness for retransmission as positive and negative pulses. At the manual exchange an incoming uniselector searches for and seizes a free position trunk relay and over the junction to the decoding relay set at the manual exchange. The coded pulses are received by special sensitive and polarized relays which in turn lock up appropriate storage relays. A further set of display relays are connected to the storage relays so that as soon as the display panel is free the combination set up in the storage relays is transferred to the display relays. The display relays now control the lamps on the position display panel. On receipt of a numerical display the operator takes up any convenient plug on the position

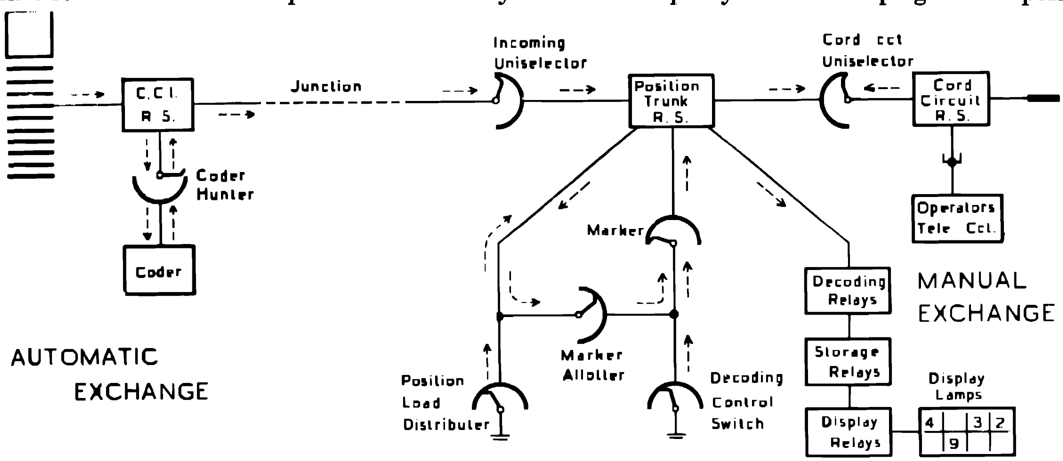


FIG. 374. CODED CALL-INDICATOR WORKING

set. The position trunk relay sets are associated with specific incoming B-positions, and a position opening distributor ensures that the incoming calls are routed to the positions in cyclic order. When the position trunk relay set is seized, a start signal is passed through a marker allotter switch to cause a marker uniselector to hunt for the calling trunk relay set. There are two or more markers per position, and the marker allotter pre-selects the markers in turn so that consecutive calls are taken up by the different markers. The marker uniselectors are connected to the banks of the decoding control switch so that the incoming calls are dealt with in originating order. When the decoding relay group is free to accept a call the decoding control switch passes a signal via the appropriate marker to the position trunk relay set. The relay set in turn relays this signal to the coder at the originating automatic exchange, and coded pulses of positive and negative current are transmitted by the coder through the C.C.I. relay set and after testing inserts it into the multiple jack of the required line. The cord circuit uniselector now rotates to find the appropriate position trunk relay set and the connexion is established for conversation. The system of markers, decoding relays, storage relays and display relays are now released for use on another call. As soon as the storage relays are free from the first call the decoding control switch makes one step to pick up the second marker and a signal is sent out to release the signals from the coder as before. By this arrangement it is possible for one call to be displayed in front of the operator, a second call to be held in the storage relays, and a further two or more calls to be held by the markers. The marker allotter, marker, and decoding control switch are so wired that calls are dealt with in strict chronological order. This queuing up of calls very considerably facilitates the staffing of the B-positions for, by this means, irregularities of traffic flow are to some extent levelled out.

EXERCISES XII

1. Explain how the traffic-carrying capacity per circuit of a large junction group is greater than the capacity per circuit of a small group. What factors limit the size of junction groups?

2. Describe how the trunk and junction network of the British Isles is designed. Show in particular how a long distance call is routed and by whom it is controlled.

3. Explain the basis on which the permissible losses in trunk, junction, and local circuits in the British telephone network are planned. (*C. & G. Transmission and Lines, Grade I*, 1944.)

4. Describe, with the aid of simple diagrams, three methods of speeding up the selection of a free circuit in a large outgoing junction group. What are the relative merits of the three schemes described?

5. What is meant by "order-wire" working? Describe in detail the operating procedure for a call routed over an order-wire junction group between two manual exchanges.

6. What are the advantages of straightforward junction working between two manual exchanges. Draw a block schematic of the arrangements.

7. Describe the various ways in which the dial on the operator's position at a manual exchange can be connected, as required, to an outgoing junction to an automatic exchange.

8. Describe a system of passing calls from a manual exchange to an adjacent automatic exchange in which the automanual exchange operator "keys up" the number required on the automatic exchange.

9. Draw a straight-line diagram to show the relative circuit positions of the sender, relay sets, etc., in a keysending system employing *four* voice-frequencies and operated from a manual exchange. Explain the principle of operation of the relays used at the automatic exchange for the reception of the alternating current at voice frequency and its conversion to a d.c. signal. (*C. & G. Telephony, Grade III*, 1945.)

10. Explain, with the help of a block diagram, the Call Indicator system of working between an automatic and a manual exchange.

CHAPTER XIII

THE PRINCIPLES OF JUNCTION AND TRUNK SIGNALLING

THE circuits between exchanges present a somewhat more involved signalling problem than the comparatively straightforward signalling to and from a subscriber. On local lines a pair of metallic conductors is always provided, but on junctions, and particularly on long trunk circuits, there is often transmission apparatus, such as amplifiers, etc., which must be considered. Moreover, with the modern trend towards the use of carrier telephony, it is becoming more and more usual for the physical conductors of a long distance circuit to be shared by a number of channels, and hence any form of d.c. signalling is impossible.

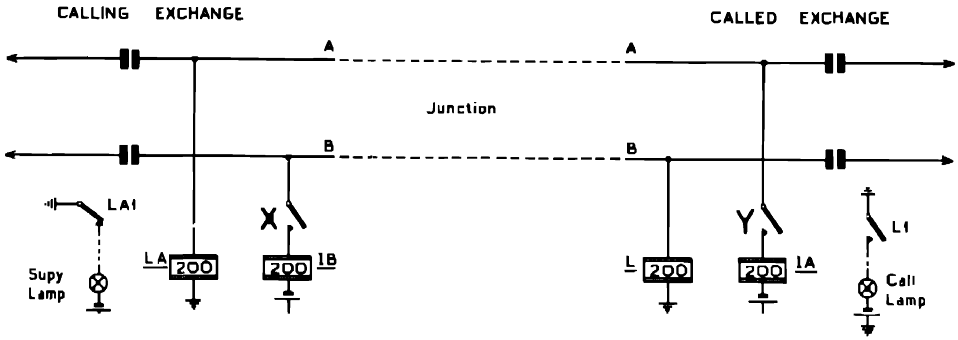


FIG. 375. PRINCIPLE OF C.B. SIGNALLING ON JUNCTIONS

In addition to the various technical difficulties, the signalling facilities on circuits between exchanges are more numerous than on local lines. In general, on trunk and junction circuits it is required that:

(*a*) the originating exchange should be able to call the required exchange;

(*b*) a supervisory signal should be returned to advise the originating operator when the incoming telephonist has answered the call;

(*c*) a supervisory signal should be returned to the originating operator when the called subscriber on the distant exchange answers;

(*d*) a clearing signal should be returned to the originating exchange when the called subscriber clears; and

(*e*) when possible, the circuit should be arranged to maintain the engaged condition on the outgoing multiple at the originating exchange until such time as the incoming operator has taken down the connexion. Alternatively, if this is not practicable, the incoming circuit at the distant exchange should be so arranged that if a second call is passed over the junction before the first call has been cleared down at the incoming end, the incoming operator will receive a proper calling signal.

Junction and trunk circuits are expensive to provide and it is of the utmost importance that all such circuits should be worked at the maximum efficiency. This requires that the ineffective time taken to set up and clear down connexions should be as short as possible and, wherever technically practicable, automatic signalling arrangements are employed. The following paragraphs describe the principles of the more common forms of signalling between exchanges.

C.B. Signalling. The transmission bridge of the Central Battery System provides battery potential to one speaking conductor and earth to the remaining speech conductor. These conditions in the cord circuit provide a ready means of obtaining d.c. signalling over junctions without the aid of subsidiary apparatus. The standard method of d.c. signalling over junctions (where the line resistance limits are suitable) utilizes the conditions sent out from a C.B. exchange cord circuit and hence is known as *C.B. signalling*. Fig. 375 shows the signalling principles. Impedance coils *LA* and *1B* are the normal impedances on the calling side of the cord circuit required for speech transmission. When the originating exchange operator inserts a plug in an outgoing jack, connexion *X* is closed and negative battery is sent out over the *B*-wire to the distant exchange. At the incoming end of the circuit, the calling battery operates relay *L* to

earth and contact *L*1 lights the calling lamp. When the called exchange answers, connexion *Y* is closed and battery is returned to the originating exchange over the *A*-wire to operate relay *LA* which at *LA*1 darkens the supervisory lamp. Relay *LA* is, of course, the ordinary cord circuit supervisory relay. As will be seen later, the return of battery on the *A*-wire when the distant exchange operator answers is readily obtained from the answering side of her cord circuit by reversing the *A* and *B* connexions to the incoming junction jack. The principle of C.B. signalling is in such extensive use that the examination of many of the circuits to be considered later in this volume will be facilitated if the two fundamental signalling conditions are memorized, viz.:

(*a*) Battery supplied over the *B*-wire to call.

(*b*) Battery returned on the *A*-wire for supervision.

The junction resistance limits for C.B. signalling are dependent upon the voltage of the signalling battery and the sensitivity of the calling and supervisory relays. For junctions between any two classes of exchange the limit is determined by the lowest signalling voltage. Typical values of maximum junction loop resistance are as follows:

Primary cell exchanges	. 800 Ω loop.
22 and 24 V exchanges	. 1300 ,, ,,
40 V exchanges	. 3600 ,, ,,
50 V exchanges	. 4800 ,, ,,
60 V exchanges	. 6500 ,, ,,

The low limit for primary cell exchanges is due to the wide variation in battery voltage at such exchanges. It should be noted that, generally speaking, the limit of C.B. signalling is determined by the sensitivity of the cord circuit supervisory relay (*LA*) rather than that of the calling relay (*L*).

Although C.B. signalling is used extensively at the present time it introduces certain difficulties on two-wire amplified circuits. On such circuits it is necessary to by-pass each amplifier by means of connexions between the line transformers as shown in Fig. 376. This by-passing frequently gives rise to balancing difficulties (see Fig. 109) and in most cases where it has been adopted there has been a degradation of the transmission efficiency of the circuit. C.B. signalling on four-wire amplified circuits (see Fig. 110) gives rise to no undue difficulty from a transmission point of view. On four-wire circuits the calling signal is transmitted on one pair, whilst the supervisory signal is returned on the second pair of the four-wire circuit. Any four-wire amplifiers can therefore be by-passed by connecting together the centre points of the line transformers on the "go" and "return" pairs as shown in Fig. 377. The balancing difficulty on two-wire repeatered circuits can be overcome by the introduction at each amplifier station of relays to receive the calling and supervisory signals and to pass on similar signals at the other side of the amplifier. This arrangement is illustrated in Fig.

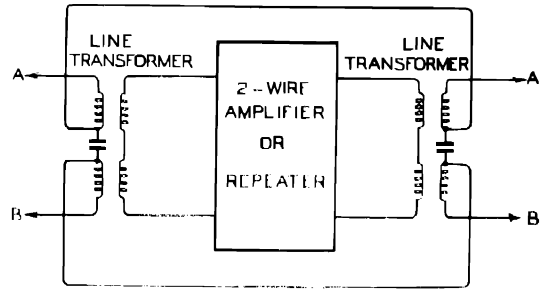


FIG. 376. METHOD OF BY-PASSING D.C. SIGNALS AT A TWO-WIRE REPEATER

378. Relay *LA* receives the calling conditions on the *B*-wire, and at *LA*1 retransmits a battery via retard *I* over the *B*-wire to the distant exchange. Similarly, a supervisory signal received on the *A*-wire operates relay *DC* which at *DC*1 returns a

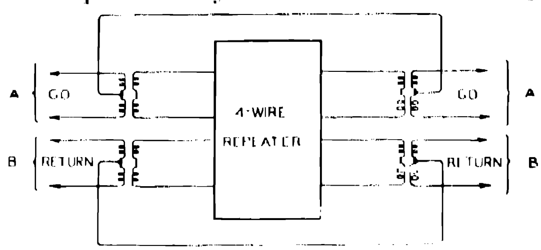


FIG. 377. METHOD OF BY-PASSING D.C. SIGNALS AT A FOUR-WIRE REPEATER

similar supervisory signal over the *A*-wire to the originating exchange. Calling and supervisory signals in the reverse direction are similarly repeated by relays *LC* and *DA*. Although this arrangement avoids the coupling together of the lines on each side of an amplifier, and incidentally also increases the overall line resistance permissible, it is not favoured on account of the maintenance difficulties resulting from the provision of signalling equipment at intermediate amplifier stations. The repetition of C.B. signalling at an intermediate amplifier station also often necessitates the provision of a special battery of suitable voltage.

Apart from the complications on two-wire amplified circuits, C.B. signalling is somewhat liable to produce disturbance on other circuits routed through the same cable. The calling signal is applied to one wire only of the speaking pair and

there is no equal and opposite current in the *A*-wire to neutralize the magnetic field. When, therefore, signalling current is started or stopped the change in magnetic field induces an e.m.f. in neighbouring conductors. The disturbance is, however, not usually serious and when present can be reduced to a negligible value by regulation of the rate of current rise by the introduction of impedance elements in the signalling circuit.

A variation of the C.B. signalling principle is

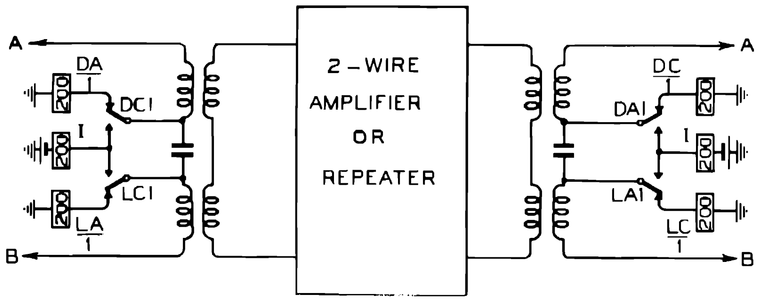


Fig. 378. Repetition of C.B. Signalling at an Amplifying Point

illustrated in Fig. 379. It is used at the incoming end of a C.B. signalling junction when there is no high voltage battery available to return the supervisory condition on the *A*-wire. Relay *L* operates from the battery received on the *B*-wire to the earth on the *A*-wire at the originating exchange. The resistance of the operate coil of *L* (10 000 Ω) is sufficiently high to prevent the energization of the supervisory relay (*LA*) at the calling exchange, but when the incoming operator replies, contact *Y* closes to place a 100 Ω coil in parallel with the operate coil of *L*. The current in the loop is now sufficient to energize the supervisory relay at the calling exchange whilst relay *L* holds on both windings in parallel. It is apparent that, with this arrangement, the line resistance limits are very considerably reduced due to the inclusion of both lines in series in the supervisory circuit.

Differential Signalling. Differential signalling is used on long junctions where the line resistance is too great for C.B. signalling. With this method, the lines are virtually connected in parallel for the d.c. signalling currents, but retard coils are of course introduced to segregate the two conductors for speech. The two facilities of calling and supervision are obtained by arranging that the normal line current in the calling condition is reduced to zero by an opposing e.m.f. at the distant end when the called exchange answers. Contact *X* (Fig. 380) is made to change over when the calling exchange takes up the circuit, and battery is applied to the *A*- and *B*-wires in parallel via one winding of *DR* and both coils of *I*. Current from the battery also flows through the second winding of *DR* and is adjusted to equal the line current by resistance *YA*. The two windings of *DR* are magnetically opposing and the relay does not operate at this stage.

At the called exchange, the line current passes via *I* through one winding of *DR* to the earth at contact *Y*. Since there is no current in the second winding to produce a neutralizing effect, *DR* operates and at its local contact ***DR*1** lights the calling lamp. When the call is answered, contact *Y* is made to change over and the battery now connected to *DR* opposes the line current. The batteries at both exchanges are of the same e.m.f. and, being opposed, reduce the line current to zero. Relay *DR* remains operated, however, by the current now flowing through its second winding to the earth at *YA*.

The absence of line current also allows *DR* at the calling exchange to operate to the current in *its* local circuit and so to darken the supervisory lamp at ***DR*1**. When the called subscriber clears, *Y* releases and the resultant line current neutralizes the effect of the current in the local circuit of relay *DR* at the originating exchange. *DR* now releases and at *DR*1 gives a clearing signal to the operator. In due course the calling operator withdraws the plug and the release of *X* restores the circuit to normal, whilst the cessation of line current allows relay *DR* at the distant termination to release, thereby giving a clearing signal to the incoming operator.

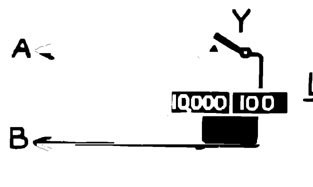


Fig. 379. Alternative Arrangements at the Incoming End of a C.B. Signalling Junction

The theoretical circuit conditions during calling, answering, and clearing are illustrated in Fig. 381. A line resistance of 5 200 Ω loop (i.e. 2 600 Ω per wire) is assumed. It will be noted that the balancing resistance *YA* (Fig. 380) must have a value equal to that of both line conductors in parallel, plus both retard coils with their windings in parallel, together with the line winding of the distant *DR* relay. With the relay and retard resistance values as shown, resistance *YA* is 700 Ω plus one quarter of the *loop* resistance of the junction.

The *DR* relay requires, for satisfactory operation, a minimum signalling current of 10 mA or a

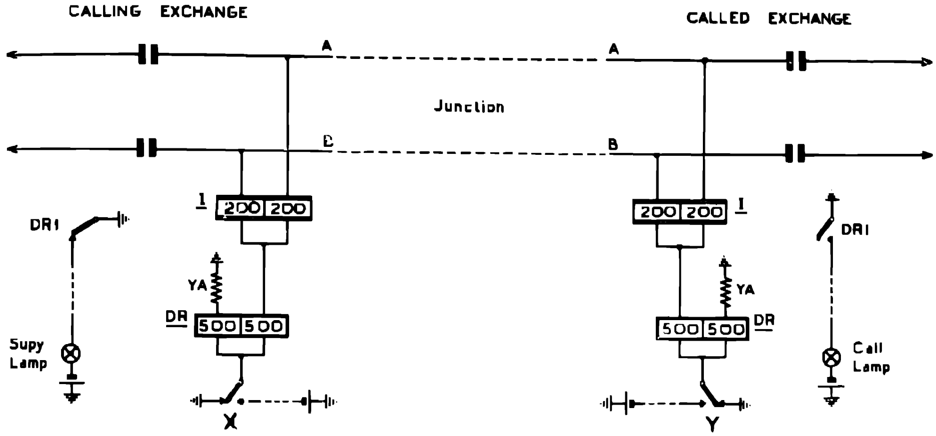


FIG. 380. PRINCIPLE OF DIFFERENTIAL SIGNALLING

minimum *difference* of 10 mA between the currents in its two windings. Assuming perfectly balanced conditions, the permissible line limits can be readily calculated. The theoretical limits for various signalling voltages are:

Signalling Voltage	Loop resistance of line (Ω)
20	3 200
30	7 200
40	11 200
50	15 200

If the junctions are worked on a four-wire basis there are four line conductors in parallel, and hence line resistance limits of almost twice the above values can be obtained.

In the ideal case the signalling voltages of the terminal exchanges should be alike in order to reduce the line current to zero during the answering condition (Fig. 381). It is interesting to examine the effect when the two voltages differ. Assume that the calling and called exchange voltages are 50 V and 40 V respectively (Fig. 382). The calling conditions are as before, but the current during clearing in the line winding of the *DR* relay at the calling exchange is now 16 mA compared with 20 mA (Fig. 381 (*c*)). Equal and opposite currents of 16 mA are applied to the *DR* relay at the called exchange. The current distribution during the conversational period is shown in Fig. 382 (*a*). It will be noted that there is a line current of 4 mA due to the voltage unbalance which produces *effective* currents of 20 − 4 = 16 mA in the calling exchange *DR* relay, and 16 + 4 = 20 mA in the *DR* relay at the called exchange. It is apparent that the *DR* relay at the exchange with the higher signalling voltage is subject to the more severe conditions, and that the line limits are determined solely by the value of the lower voltage. Fig. 382 (*b*)

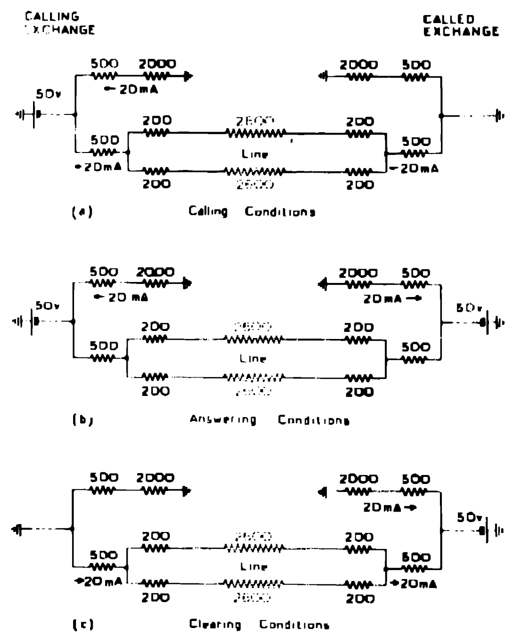
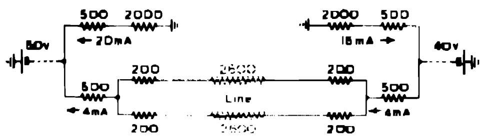


FIG. 381. BASIC CIRCUIT CONDITIONS OF DIFFERENTIAL SIGNALLING

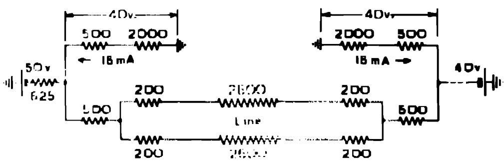
shows the effect of attempting to reduce the line current to zero during the answering condition by inserting a voltage dropping resistance in series with the higher voltage. The effective current in both *DR* relays is now 16 mA, i.e. the conditions

for the calling exchange *DR* relay are not improved whilst the effective current in the distant exchange *DR* relay is now 16 mA as compared with 20 mA before equalization of the line current.

In order to simplify the application of the differential signalling principle to field requirements, a signalling voltage of 50 V has been standardized. If the exchange battery is less than 50 V, the e.m.f. is made up by adding primary or small secondary cells in series with the exchange battery. To prevent excessive current in the *DR* relay on the shorter junction lines (under 3600 Ω loop), a resistance is inserted in series with the signalling battery to limit the line current to 20 mA.



(*a*) Line current due to unbalanced battery potentials.



(*b*) Effect of neutralizing line current.

FIG. 382. EFFECT OF UNEQUAL BATTERY POTENTIALS ON A DIFFERENTIAL SIGNALLING CIRCUIT

Since both conductors of a differential signalling circuit always have equal potentials, this method of signalling is quite satisfactory from a transmission aspect and does not introduce the difficulties present with C.B. signalling on repeatered and amplified lines. In the past few years it has been extensively used, especially to give automatic signalling facilities on routes which have been diverted to underground cables having a resistance above the limit for ordinary C.B. signalling.

Loop Signalling. A system of loop signalling is often employed between an automatic exchange and a distant manual board. The calling condition on such circuits is a loop on the *A*- and *B*-lines at the automatic exchange, with the battery and earth supply via a calling relay at the manual termination. The supervisory signal when the operator or the called party replies is a reversal of the battery and earth conditions returned from the manual exchange. Fig. 383 shows the elements of a loop signalling circuit. When contact *X* is closed at the originating exchange the *A*- and *B*-wires of the junction are looped via impedance coil *I* and the *D* relay. The loop so formed energizes relay *L* at the called exchange which at **L1** lights the calling lamp. The rectifiers associated with relay *D* prevent the operation of *D* during the calling condition. When the distant operator answers, however, contacts *Y* change over the connexions of the *L* relay coils and reverse the current in the line. Relay *D* now operates to darken the supervisory lamp or, when the originating exchange is automatic, to meter the call against the subscriber. It will be noted that impedance coil *I* is necessary to maintain a high impedance to speech currents through the shunt path formed by the *D* relay and rectifiers. In a large number of circuits a shunt field relay has been used in place of the simple relay with metal rectifiers.

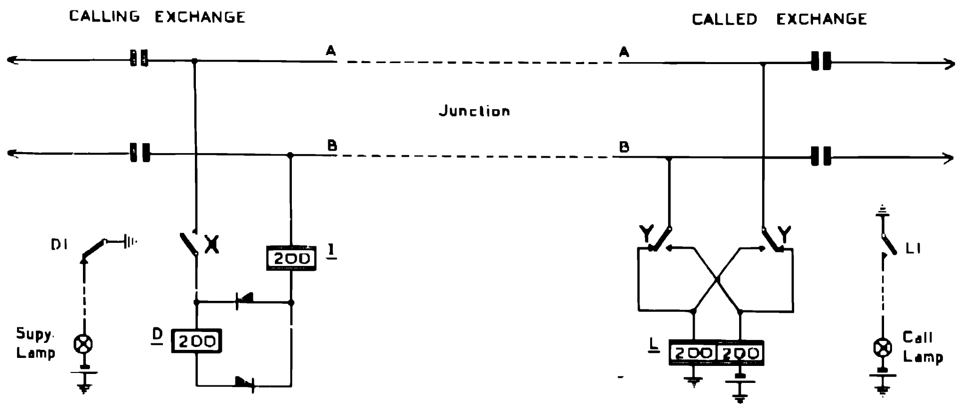


FIG. 383. PRINCIPLE OF LOOP SIGNALLING

It is apparent that for the same signalling battery voltage and a given sensitivity of the calling relay, loop signalling does not permit of so high a junction

resistance as C.B. signalling. In C.B. signalling the resistance of only one wire of the junction is included in the signalling circuit, whereas in loop signalling the effective resistance to the signalling currents is the loop resistance of the junction. On the other hand, loop signalling is far less likely to produce disturbance in adjacent conductors due to the fact that the magnetic effect of the current in one wire is substantially neutralized by the equal and opposite current in the remaining wire of the junction.

Manual Hold. On calls from a remote automatic exchange to its parent manual board, metering is not normally required. In these circumstances the supervisory signal when the incoming operator answers is utilized to hold the calling subscriber for so long as the operator's plug remains in the jack. This *manual hold* facility is standard on all "0" level calls and provides a valuable means of holding a calling line for the verification of a subscriber's number, etc. The simplified circuit arrangements are illustrated in Fig. 384. When the outgoing junction to the manual board is seized by the automatic subscriber, relay *L* operates and at ***L*1** energizes relay *B*. ***B*1** in turn provides an earth to hold the switches in the automatic exchange. ***L*2** completes the calling loop to the parent manual board and relay *LA* at the incoming termination operates to the loop current. ***LA*1** lights the calling lamp as before. The loop current also energizes relay *MH* which provides a second hold circuit for relay *B* at ***MH*1**. When the operator answers, contacts *Y* change over to reverse the connexions of relay *LA* to line. This reversal has no immediate effect and relay *MH* (after a momentary release during the reversal) remains held to the loop current. If now the calling subscriber replaces his receiver, relay *L* releases and the loop circuit is broken at *L*2. Relay *MH* now holds from the earth at *L*2 via the positive line of the junction to battery through one coil of relay *LA*. (Contacts *Y* are operated.) ***MH*1** holds the *B* relay to maintain the hold condition on the automatic selectors. Relay *B* is made slow to release in order that it shall remain operated during the momentary disconnexion of *MH* when contact *L*2 restores. The calling subscriber is now held until such time as the operator withdraws the plug and allows contacts *Y* to restore. *MH* now releases and at *MH*1 removes the hold circuit from relay *B* and the holding condition at *B*1.

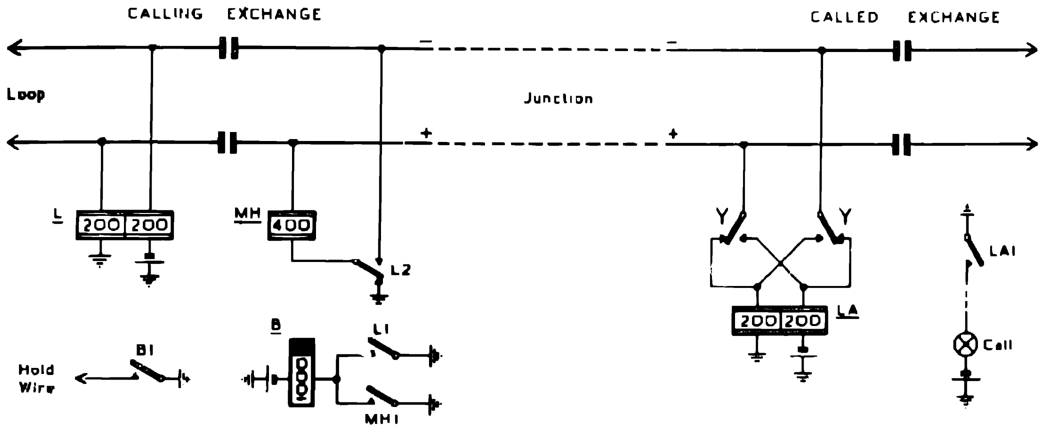


FIG. 384. PRINCIPLE OF MANUAL HOLD

Coin-box Discrimination. If the number of "0" level circuits from an automatic exchange is small, it is preferable, on grounds of circuit efficiency, to provide a common group of junctions to carry the "0" level traffic both from ordinary and from coin-box subscribers. When this arrangement is adopted means must be provided for advising the manual board operator when a call originates from a coin-box subscriber in order that she can collect the necessary fee. Two distinctive calling signals are now required throughout the automatic equipment and over the junction. Usually the normal loop is retained for calls emanating from an ordinary subscriber, whilst an earthed loop is provided on calls from coin-box lines. The simplified arrangements of an "0" level circuit with coin-box discrimination and manual hold facilities are given in Fig. 385. If the call emanates from an ordinary subscriber, relays *L* and *LC* are both operated from the calling loop. ***LC*2** completes the loop over the junction, whilst ***L*1** removes the earth from the calling loop. At the parent exchange, relays *LA* and *LB* operate in

series with the loop and the "ordinary" calling lamp is lighted via **LB1** and **LA1**.

If the call is from a coin-box subscriber, the earthed loop extended through the automatic switches allows relay *LC* to operate, but relay *L* is short-circuited by the earth. **LC2** completes the junction loop as before but, since relay *L* is not now operated, the earth from *MH*2 is also applied to the calling loop. At the manual exchange, relay *LB* operates but *LA* cannot operate due to the presence of the earth. The calling condition is therefore routed to the "coin-box" calling lamp via **LB1** and *LA*1. When the operator answers, contacts *Y* change over and manual hold conditions are returned to the automatic exchange as described above.

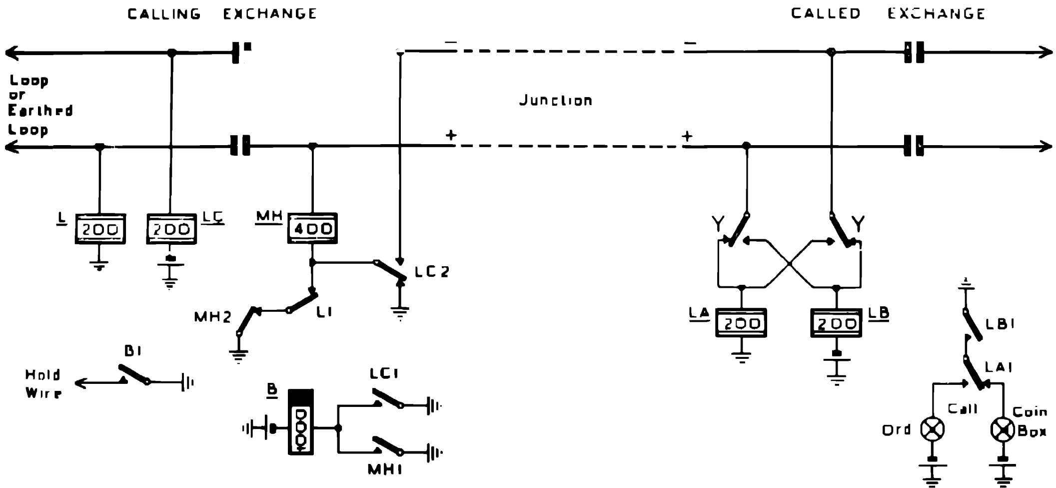


FIG. 385. TYPICAL COIN-BOX DISCRIMINATION CIRCUIT

There are several other arrangements of d.c. signalling over junctions between a remote automatic exchange and its parent manual board. Possibly the most complex arrangement occurs when a common group of junctions is provided to carry not only ordinary and coin-box "0" level traffic but also to route a call, when required, through the automatic equipment at the parent exchange. These more complex junction signalling methods are considered later in Volume II.

Use of Rectifiers to Prevent False Signalling. In some circuits, particularly bothway junctions, earth or battery connected relays are applied to both ends of the same wire. These relays usually form part of entirely separate signalling circuits, but their presence together on the same conductor tends to produce false signalling if there is any difference between the battery voltages or earth potentials at the terminal points. The difficulty can often be overcome by introducing metal rectifiers into the circuit in such a way that they do not interfere with normal signalling currents but at the same time they provide an effective block to unwanted currents. Fig. 386 shows typical conditions on a bothway junction. Relay *BY* is connected to the *B*-line at exchange *Y* to receive a calling battery from exchange *X*. Relay *BX* is also connected to the *B*-line to receive a similar calling signal from exchange *Y*. It is apparent that, when the circuit is idle, a difference of earth potential between *X* and *Y* will produce a current through *BX* and *BY* if the rectifiers are omitted. The current may, in some cases, be sufficient to operate one or both of the relays. The rectifiers, introduced as shown, effectively prevent any such currents but offer a very low resistance to authentic signals.

On the *A*-line, relays *AX* and *AY* are provided to receive earth signals from exchange *Y* or exchange *X* respectively. If the metal rectifiers are omitted from this circuit, any difference of p.d. of the two exchange batteries will produce an unwanted current through *AX* and *AY*. Here again the metal rectifiers prevent the passage of irregular currents through the signalling relays but do not affect normal signals.

Generator Signalling. If the resistance of a line will not permit of the employment of any of the direct current methods already considered, resort must be made to some form of alternating current signal. Magneto ringing by virtue of its high e.m.f. can be used over lines of high resistance where it is not possible to obtain sufficient current for the employment of d.c. signalling. Although it is now

rapidly being superseded by voice-frequency signalling, magneto signalling is still used on a number of long distance circuits. It is impracticable, however, without undue complication of the terminal equipment, to provide automatic calling and supervisory signals on a ringing basis, and hence generator signalling is only used as a last resource when d.c. or other automatic signalling arrangements cannot be provided. The operator on taking up a generator signalling circuit must manually ring the distant exchange and must listen on the circuit until the called exchange replies. Similarly at the termination of a call the incoming operator must "ring off" to the calling exchange in order that the latter can take down the connexion. Such signals are erratic and make inefficient use of expensive trunk lines. The ring-off signal is, in fact, so unreliable that in modern practice it is eliminated and a permanent clearing signal is given to the operator on all generator signalling circuits.

The principle of generator signalling is illustrated in Fig. 387. Contacts *X* apply 17 c/s ringing current to line when the originating exchange desires to call. At the incoming end, the ringing current is received on an a.c. relay which, in modern practice, is usually in the form of a rectifier shunted relay of the standard type. The line relay (*L*) operates a relief relay at *L1* and the relief relay (*LL*) locks to its own contact and lights the calling lamp at *LL2*. If the called exchange wishes to recall the originating exchange or if "ring off" facilities are required at the end of a call, contacts *Y* change over and ringing current is now applied to the line at the called exchange to operate the a.c. relay in the calling exchange termination. A relief relay *LL* is again provided and *LL2* lights the clearing lamp at the originating exchange. It will be noted that generator signalling circuits are automatically

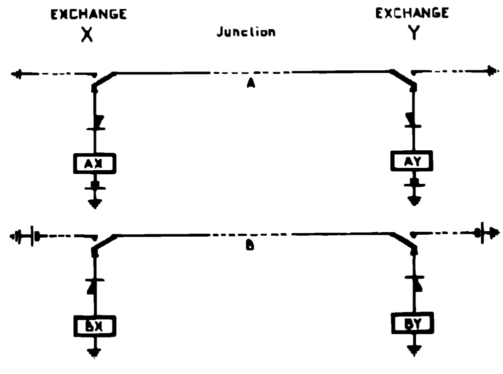


FIG. 386. USE OF RECTIFIERS TO PREVENT FALSE SIGNALLING DUE TO DIFFERENCES OF EARTH OR BATTERY POTENTIAL

"bothway" in character, i.e. they are symmetrical at both the calling and called exchange ends of the circuit.

Generator signalling has in the past been used extensively on long distance trunk circuits. The resistance limit of the signalling path is usually in the order of about 5000 Ω. On two-wire circuits, when this figure is exceeded signalling current is relayed at each repeater station in a manner somewhat similar to the direct current repetition for C.B. signalling shown in Fig. 378. On four-wire amplified circuits the 17 c/s can either be by-passed

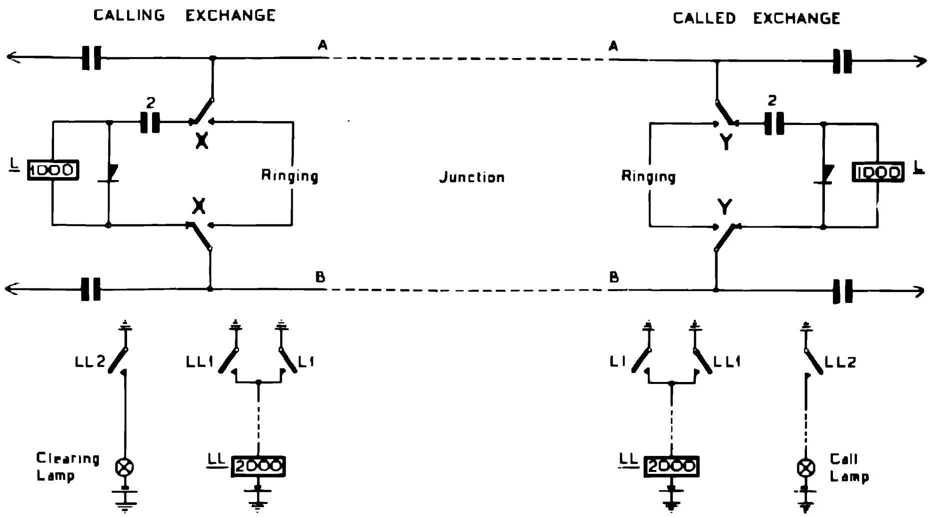


FIG. 387. PRINCIPLE OF GENERATOR SIGNALLING ON JUNCTIONS

as in Fig. 377 or, if regeneration of the signal is required, a relaying equipment as for the two-wire circuit may be used. Seventeen c/s ringing is undesirable from a transmission point of view on account of the line noise, ringing induction and crosstalk introduced in both cables and amplifiers. In particular it is difficult to avoid severe ringing induction due to the high voltages impressed on the grids of the amplifying valves during ringing. The interference from ringing could no doubt be

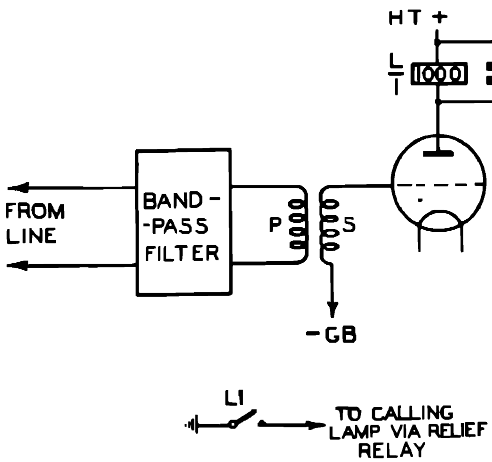


FIG. 388. SIMPLE RECTIFIER CIRCUIT

reduced by the provision of low-pass filters on ringing machines, the troublesome higher frequencies being suppressed before transmission. Similarly, amplifiers and repeaters could be made unresponsive to the fundamental 17 c/s wave by the use of corresponding high-pass filters.

It is improbable that extensive developments of this method of signalling will occur in the future due to the fundamental lack of automatic signalling facilities. Seventeen c/s signalling has in fact now been largely superseded on the long zone to zone centre circuits by an automatic method of signalling employing voice-frequency currents.

Voice-frequency Signalling. On long underground circuits and particularly with loaded cables, the attenuation of 17 c/s signalling current is very high, and with such circuits frequent repetition or regeneration of the signalling current is necessary. Moreover, the recent extension of carrier working considerably reduces the field of application of 17 c/s ringing as it is difficult to arrange for the frequency conversion and subsequent demodulation of so low a frequency. The use for signalling of alternating current within the voice-frequency range avoids all transmission difficulties since the signalling currents are basically similar to those of normal speech and can be transmitted over the usual speech paths. Such signalling currents are, of course, amplified at the same intervals and to the same degree as speech currents. Hence, a much smaller initial power is required with the consequent reduction of interference between adjacent pairs in the same cable.

The use of alternating currents within the voice-frequency range introduces certain new signalling problems. The first is to find a satisfactory means of detecting incoming signals of small power. In addition, adequate safeguards must be provided to ensure that the signalling apparatus does not respond to speech itself. A third and possibly the greatest complexity occurs due to the fundamental fact that voice-frequency signalling currents cannot, for obvious reasons, be passed over the line during the conversational time.

A further complication arises due to the presence of echo suppressors on long distance trunk circuits. It was shown in Chapter V that devices are necessary on long four-wire repeatered circuits to prevent speech transmitted from one end being returned along the receive pair to give an echo effect. The echo suppressors automatically degrade the transmission on the receive pair when speech is being passed on the transmit pair, and vice versa. Hence, if a continuous voice-frequency signal is being transmitted, it is impossible concurrently to pass a similar signal in the opposite direction. It follows that any system of voice-frequency signalling must be arranged so that the signal is interrupted periodically in order to allow a signal in the opposite direction to be transmitted.

Detection of Voice-frequency Signalling Currents. Relays of the type described in Chapter VII which are mechanically tuned to a predetermined frequency in the voice range have been used successfully for several forms of voice-frequency signalling. They have, however, the inherent disadvantage of requiring critical adjustment, and they will in practice only function satisfactorily if the operating current is within fairly close limits. In modern practice, electrical filters in conjunction with valve equipment are largely superseding tuned relays, although it must be remembered that the cost of the latter is generally much less than that of valve equipment, and hence tuned relays may have a limited field of usefulness in the future under conditions where the cost is important and where the operating requirements are not severe.

A simple valve circuit for the detection of voice-frequency signals is shown in Fig. 388. At the incoming end of the circuit the voice-frequency tone is isolated by means of a band-pass filter which is designed to transmit a narrow band of

frequencies but to offer a high attenuation to currents of other frequencies outside this band. The selected tone is applied via an input transformer to the grid of the rectifying valve. In the static condition the grid of the valve is given sufficient negative bias to reduce the anode current to a value approaching zero (Fig. 389), but the

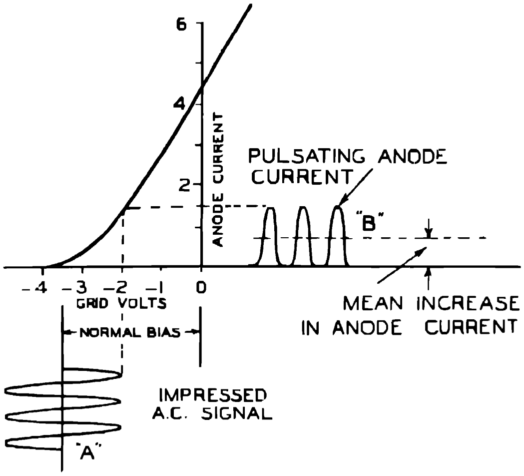


FIG. 389. ANODE CURRENT RESULTING FROM A.C. SIGNAL ON GRID OF VALVE

injection of an alternating potential "A" into the grid circuit produces a surge of anode current as shown at "B" during each positive half-cycle of the applied e.m.f. The negative half-cycles do not produce a change of anode current owing to the bend in the valve characteristic at the point corresponding to the normal bias voltage. The pulsating unidirectional anode current resulting from the small a.c. voltage applied to the grid of the valve may be considered as a steady current on which an alternating component of double the signal frequency is impressed. The alternating component is by-passed back to the cathode of the valve by means of a suitable condenser, and the steady d.c. component is used to operate a relay connected in the anode circuit. The relay is adjusted to operate with the increase in mean anode current on receipt of a signal, and its local contacts operate a relief relay which in turn controls the calling lamp or other d.c. signalling circuit.

This simple rectifier circuit (which is incidentally identical with the anode-bend rectification sometimes employed in radio receivers) is of little value in practice owing to its comparative insensitivity. An incoming signal of good strength may produce a comparatively small anode current, and with such a detecting device it is necessary to employ one or more stages of amplification before applying the signal to the rectifier. Moreover, even if pre-amplification is economically practicable, the resultant anode current varies considerably with slight changes in the strength of the received signal, and hence the relay must be designed to function satisfactorily over a very wide range of operate currents.

In modern voice-frequency receiving equipment, various devices are introduced to improve the sensitivity and to make the receiving unit as independent as possible of the strength of the incoming signal. The development of the valve rectifier circuit, known as *rectified reaction,* was introduced some years ago and is now used as the basis of most practical V.F. signalling circuits. The principle in its simplest form is shown in Fig. 390. As before, the incoming V.F. signal is selected by a band-pass filter and is applied via the 0·2 μF condenser to the grid of the rectifying valve. The valve is biased to give almost zero anode current in the static condition, and hence each positive half-cycle of e.m.f. applied to the grid produces a pulse of current in the anode circuit. The d.c. component of this pulsating current passes through relay *L* and, as in the previous circuits, tends to operate it. The a.c. component is, however, utilized by allowing it to pass through the primary of a transformer which is included in the anode circuit. The secondary of the transformer is connected in series with a metal rectifier across the

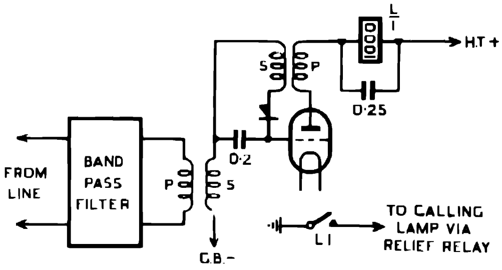


FIG. 390. SIMPLE DETECTOR CIRCUIT WITH RECTIFIED REACTION

0·2 μF grid condenser. By this means the alternating e.m.f.s in the anode circuit are stepped up by the transformer and are rectified to give a pulsating charging current to the condenser. On receipt of an incoming signal, the p.d. across the condenser is rapidly increased due to consecutive applications of pulses from the anode circuit until the effective bias on the grid of the valve is reduced almost to zero. At this point grid current commences to flow, and a stable condition is reached when the positive pulses applied to the condenser

balance the discharge of the condenser due to grid current. The net result of rectified reaction is to produce an anode current, on receipt of a signal, equivalent to that which would be produced at zero grid bias volts. This anode current is very many times larger than the original increase of current produced by the incoming signal alone and, more important still, it is substantially independent of the strength of the incoming signal. A comparison of the increase in anode current with and without rectified reaction is given by the curves shown

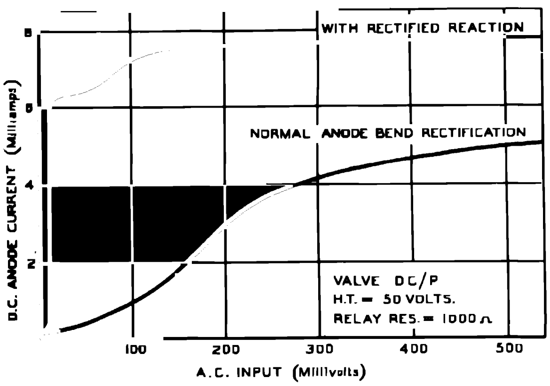


FIG. 391. ANODE CURRENT WITH VARIOUS A.C. INPUT VOLTAGES

in Fig. 391. It will be noted that with rectified reaction the current rises very rapidly to some 6 mA and then remains substantially constant and independent of the input voltage. The practical detector circuits are somewhat more elaborate than the elementary arrangements given, and usually make use of full wave rectification in the feed-back circuit. These practical circuits are considered in detail in Volume II.

Prevention of False Operation due to Speech. The danger of false operation of V.F. signalling devices by ordinary speech has been one of the main troubles experienced in the development of this method of signalling. The methods of protection adopted in each case do in fact account to a large extent for the main differences between various V.F. signalling systems. In general, the method employed for the discrimination between signal and speech currents is based on one or a combination of the following principles:

(*a*) In speech, as is well known, a particular frequency is not maintained for any appreciable length of time. A delay device which requires the V.F. signal to be maintained for a predetermined time would therefore materially reduce the possibility of false operation due to speech.

(*b*) The adoption for signalling of a complex wave produced by combining two or more frequencies so chosen that the wave is unlikely to be imitated by speech.

(*c*) The rapid interruption or modulation of the tone to make a distinctive signal which is not likely to be imitated by speech.

(*d*) An arrangement of the incoming circuit so that if the signal frequency alone is received, the equipment responds, but if other frequencies in addition to the signal frequencies are present, the incoming circuit is rendered ineffective. This method relies on the fact that in practice speech never consists of one note only, but is invariably a complex wave consisting of numerous frequencies.

The adoption of a delay circuit based on principle (*a*) was the subject of a patent issued as long ago as 1917, but it was found from experience that, to ensure reasonable immunity, the delay must be in the order of seconds. The use of a complex signalling wave (*b*) has been tried with some measure of success, but this system has not been favoured to any great extent in this country. A 500 c/s voice-frequency ringing current interrupted 20 times a second has been used successfully for ringing over long distance trunk circuits. The detector circuit on this system responded to the 500 c/s current, and the 20 c/s pulses were applied to a relay mechanically tuned to this frequency. Thus, although the 500 c/s detector circuit might respond to speech, the 20 c/s relief relay would not record the signal unless the relay were pulsed at the correct frequency.

Whilst it can be said that methods (*a*), (*b*), and (*c*) can be made to guard satisfactorily against speech, it has been found that method (*d*) in conjunction with method (*a*) offers the best solution to the problem. This combination is the principle on which most modern V.F. receivers are designed.

500 c/s Ringing. Voice-frequency signalling in the form of 500 c/s ringing current has been used for a number of years on long amplified trunk lines on which normal generator signalling is sent out by the terminal exchanges. 500 c/s ringing does not in any way provide automatic signalling facilities, but merely converts the 17 c/s ringing current sent out from the exchange to 500 c/s voice-frequency current for transmission through the various amplifiers of the trunk line. Fig. 392 shows the elements of a 500 c/s ringing converter. The conversion is, by the way, usually carried out at the first repeater station from the terminal exchange and not at the exchange itself. 17 c/s ringing current sent out from the exchange operates relay *F* which is connected in a rectifier bridge circuit. **F1** operates *G* and contacts **G1** and **G2** in turn send

out to line the 500 c/s ringing signal. The modern type of conversion unit relies upon a combination of a delay feature and the absence of certain extraneous frequencies for distinguishing a genuine signal from normal speech. The signalling current can therefore be a simple unmodulated note of

An incoming 500 c/s signal from line is applied to the input of a two-stage amplifier. The output circuit of this amplifier consists of three resonant circuits in parallel. The first is tuned to 500 c/s, the second to 600 c/s, and the third to 750 c/s. Relay *A* is connected through a rectifier bridge to

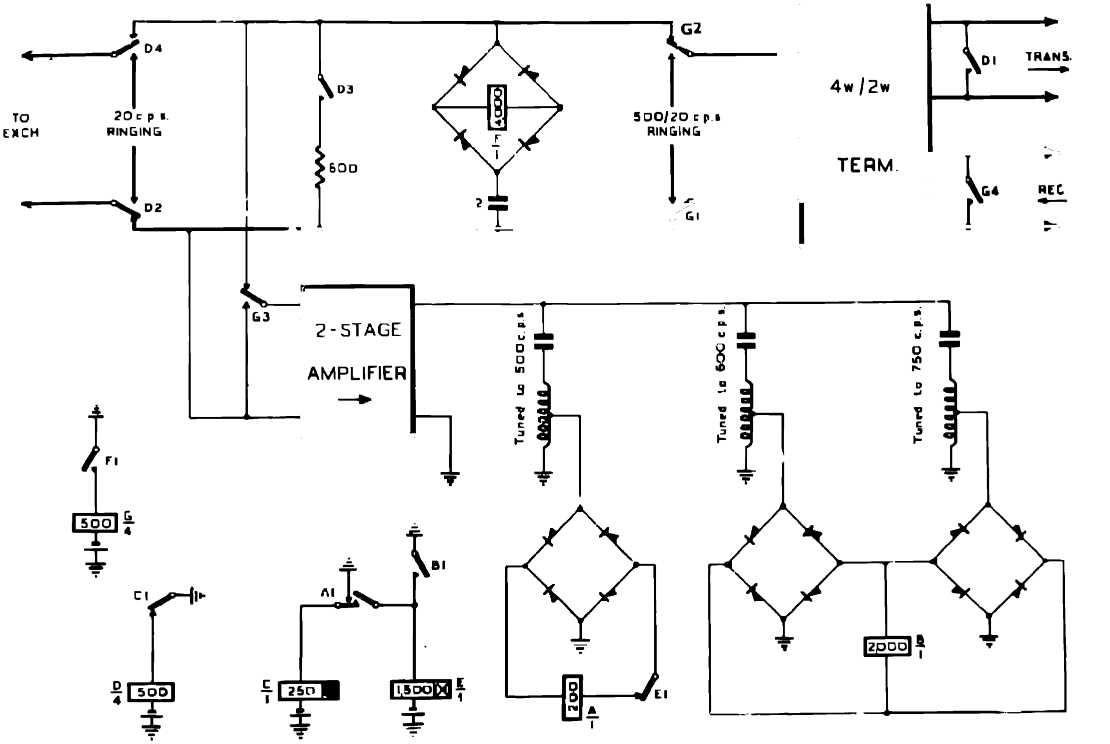


FIG. 392. 500/20 C/S CONVERSION CIRCUIT

500 c/s, but it is standard practice to utilize a signalling current of 500 c/s interrupted 20 times per second in order to cater for some of the older types of receiving equipment which rely upon the 20 c/s modulation for discrimination purposes.

The internal impedance of the 500/20 c/s supply is 600 Ω, and on most lines the application of this impedance at **G1** and **G2** to the two-wire circuit will maintain stability. On long trunk lines of high characteristic impedance, however, it is necessary to introduce contact **G4** which short-circuits the receive pair of the four-wire circuit to prevent circulating current due to out of balance conditions during ringing. Contact **G3** short-circuits the input to the amplifier and disconnects the amplifier from the speaking pair in order to prevent false operation of relays *A* and *B* due to the very high 17 c/s signalling voltage sent out from the exchange.

the 500 c/s tone circuit, whilst relay *B* is similarly connected to both the 600 and 750 c/s circuits. If the incoming current is a true signal, relay *A* operates but relay *B* does not. **A1** releases *C* and *C1* in turn operates *D*. Contacts **D2** and **D4** apply 20 c/s ringing to the exchange, whilst **D3** connects a 600 Ω terminal impedance to replace that of the exchange termination. As before, it may so happen on long trunk circuits that the 600 Ω impedance does not provide an accurate balance. Contact **D1** is then connected to short-circuit the transmit pair to prevent circulatory currents.

Protection against false operation by speech currents is provided by relay *B* and by the release lag of relay *C*. A speech voltage of 500 c/s will usually also contain frequencies of 600 and 750 c/s. Both relay *A* and relay *B* therefore operate, but contact **B1** now holds relay *C* after the operation of **A1** and so prevents the operation of the *D* relay.

It is, moreover, extremely unlikely that a speech voltage of 600 c/s will persist for the 400 msec or so lag of relay *C*. Apart from the operation of *B*, therefore, relay *C* cannot release unless *A*1 is operated for a period equal to the release lag of *C*. A further safeguard is provided by relay *E* the contact of which (*E*1) prevents the operation of *A* for a delay period after the operation of *B*.

There are several refinements in the practical circuit such as, for example, a limiting device in the second stage of the amplifier to even out the

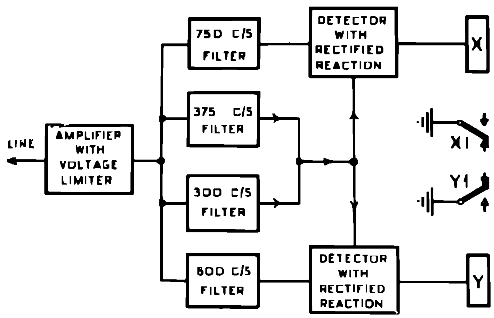


FIG. 393. GENERAL ARRANGEMENTS OF 2 V.F. RECEIVER

levels of received tones. The *B* relay is also of the twin-coil type with the second coil partially energized through contacts of relay *E*. On the operation of *B*, the *E* contacts reverse the current in the second winding and so prevent relay *B* being held, after operation by speech, from low level signals such as noise.

2 V.F. Signalling. A system of automatic signalling using voice-frequency currents has been developed in recent years for application to long trunk routes which were hitherto worked on a 500/20 c/s ringing basis. Two frequencies of 750 c/s and 600 c/s, known as the *X*- and *Y-tones* respectively, provide the basic signalling currents. The X frequency is used for calling or flashing from the originating exchange, whilst the Y frequency is reserved for clearing or flashing from the called exchange. Unlike automatic d.c. signalling systems, it is not possible to leave the calling signal on the line throughout the conversation and to disconnect it to provide a clearing signal at the end of the call. The calling signal is therefore a short pulse of X frequency when the plug is inserted in an outgoing jack and, at the end of the call when the plug is removed, a special clearing signal consisting of a long pulse of X-tone followed immediately by a short pulse of Y-tone gives the clearing signal to the incoming operator. The prohibition of V.F. signalling current during the conversational time (except for flashing) also prevents the usual form of supervisory or answering signal. In the 2 V.F. system the circuit is so arranged that Y-tone is returned by the incoming exchange immediately a calling signal is received. The tone is discontinued when the operator answers and again when the called subscriber replies, but is restarted when the incoming operator flashes and when the called subscriber clears. In order to allow the passage of signals from the originating exchange concurrently with the transmission of Y-tone from the called exchange, the latter is interrupted for some 360 msec every half-second, thereby restoring the echo suppressors on the transmission line.

In addition to providing automatic calling and clearing with operator recall facilities, 2 V.F. signalling also provides an extended engaged test condition on the outgoing multiple until such time as the plug is removed from the incoming jack. The signalling condition is a continuous and uninterrupted Y-tone which starts when the clearing signal is received at the incoming termination and stops when the plug is removed from the incoming jack.

Voice-frequency Receiver. The voice-frequency receiving unit used on the 2 V.F. signalling system is permanently connected across the speaking pair and is designed to introduce a minimum transmission loss. For the sake of uniformity, the receivers at each end of the trunk line are identical. Fig. 393 shows the general arrangements of the standard receiver. The incoming signals from line are first passed through an amplifier which also acts as a voltage limiter to make the output substantially constant for a large range of input level. The amplified signal is then applied to a system of four tuned circuits designed to pass frequencies of 300 c/s, 375 c/s, 600 c/s and 750 c/s. The 750 c/s and the 600 c/s filters accept the X and Y signalling tones respectively and pass on the signals to a valve detector circuit for each frequency. The detector circuit incorporates the rectified reaction principle and on the receipt of a signal, relay *X* or *Y* is energized. Contacts of these two relays in turn control the d.c. signalling circuits at the line termination. Some degree of immunity from speech operation is provided by the initial voltage limiter for, if the signal frequencies in the line are mixed with other frequencies, the output from the valve contains a relatively small amount of signal frequency. Provision is also made to render the signal detection stages inoperative if frequencies of 300 c/s and 375 c/s (the first sub-harmonics of the Y- and X-tones) are present in the line current. The output from the 300 c/s and 375 c/s filters is rectified and is applied to give a bias to the suppressor grids of the detector stages. Further pro-

tection against speech operation is provided on the d.c. side of the signalling arrangements where a delay feature is introduced to prevent operation of the calling relays, etc., unless the tone is maintained for a predetermined period.

Calling Conditions. Fig. 394 shows in greatly simplified form the calling conditions of a 2 V.F. signalling circuit. It will be noted that a uniselector is provided at the outgoing end of the circuit to control the sequence of operations. When the plug is inserted in an outgoing jack, relay *M* operates and at *M*1 causes the uniselector to drive on to the first contact. Relay *FXY* is now operated over arc 1 and at *FXY*1 sends out X-tone to line. *FXY*2 provides a further drive circuit for the uniselector which now moves to the third working contact. Relay *FXY* is therefore operated whilst the wipers are passing over the first and second contacts, and tone is applied to the line for this period plus the release lag of the *FXY* relay—a total time of approximately 100 msec.

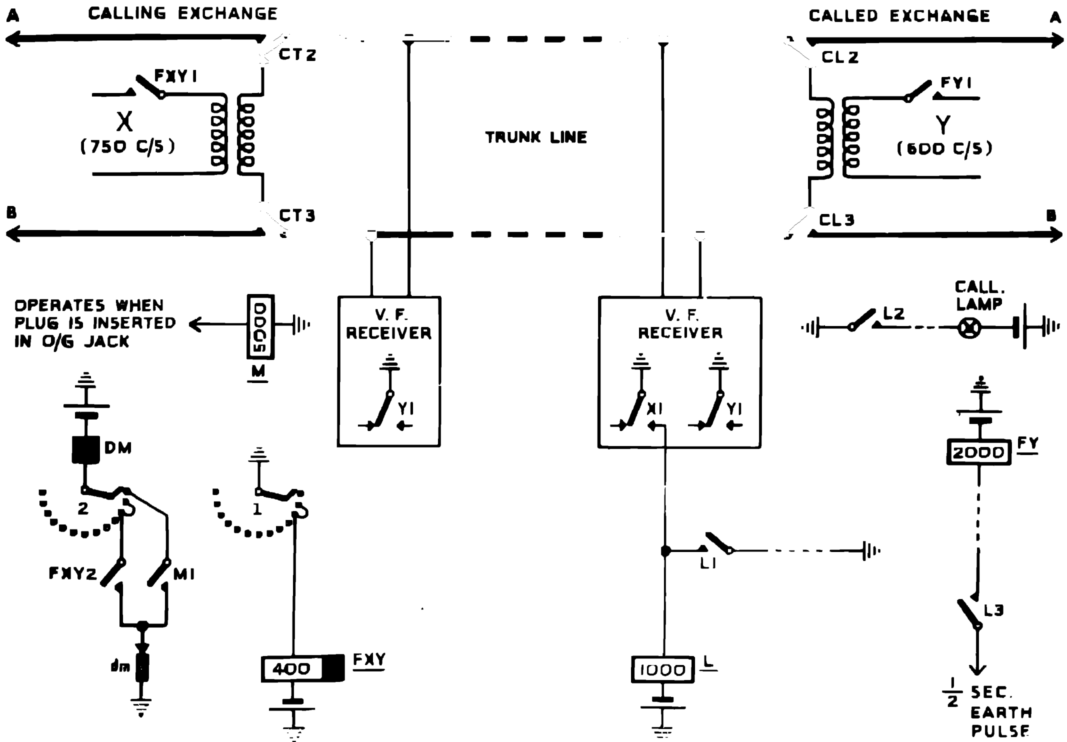


FIG. 394. CALLING CONDITIONS
(2 V.F. Signalling)

The calling signal operates relay *X* in the V.F. receiver at the incoming termination and *X*1 energizes relay *L*. *L*1 provides a locking circuit for *L* whilst *L*2 lights the calling lamp. At the same time contact *L*3 applies a half-second earth pulse to relay *FY* which now returns Y-tone back to the originating exchange during each operation of *FY*. By this means a series of Y-pulses each of 140 msec duration and separated by 360 msec intervals of no tone are returned to the originating exchange.

Supervisory and Flashing Conditions. The Y-pulses from the incoming exchange continue until such time as the incoming operator answers the call and throws the cord circuit speaking key. Relay *CL* (Fig. 395) now operates and at *CL*1 breaks the circuit of *FY* to disconnect the Y-tone signal from the line.

At the outgoing end of the circuit relay *RS* operates when the first pulse of Y-tone is received, and during the ensuing period of no tone relay *RD* is energized via *Y*1 and *RS*1. The *RS* and *RD* relays are slow to release and are arranged so that *RD* is held operated for so long as Y-pulses are received. When the incoming operator answers and the train of Y-pulses ceases, relay *RS* releases after a delay period, and at RS1 allows RD to release. By this time the control uniselector has moved to the fifth contact, and relay *CT* now operates from arc 1 of the uniselector via *RR*1 and *RD*1.

CT*2** and ***CT*3** disconnect the signalling circuit and switch through the lines for conversation. ***CT*4** darkens the supervisory lamp at the outgoing exchange. Restoration of the speaking key at the incoming position allows *CL* to release and the *Y*-pulses to restart until such time as the called subscriber replies. *CL* now re-operates and switches by the incoming operator energizes ***RR which at ***RR*1** disconnects *CL*. *CL*2 and *CL*3 switch the circuit from the speaking to the signalling conditions, whilst *CL*1 allows relay *FY* to pulse and send out a continuous stream of Y-pulses for so long as the flashing key is operated. At the outgoing end of the circuit, the re-operation of contact ***Y*1** (V.F. receiver) operates *RS* and at the first break period, the release of *Y*1 re-operates *RD*. ***RD*1** now transfers the holding circuit of *CT* to the earth at *Y*1. The next operation of ***Y*1** breaks the circuit for *CT* which now releases—relays *RS* and *RD* being held for so long as the Y-pulses are received. *CT*2 and *CT*3 disconnect the speech circuit to prevent the line signals reaching the calling subscriber, whilst *CT*4 lights the supervisory lamp on the outgoing position. At the end of flashing the Y-signals cease, *RD* restores, and *CT* re-operates to the earth at arc 1 of the uniselector. It will be noted that the *RS* and *RD* combination prevents the release of *CT* after a short false pulse of Y-tone on the line. It is, in fact, necessary for *Y*1 to operate, release, and re-operate before *CT* can be released. Similar protection is provided at the incoming end of the circuit by the slow release of *GX*, which prevents

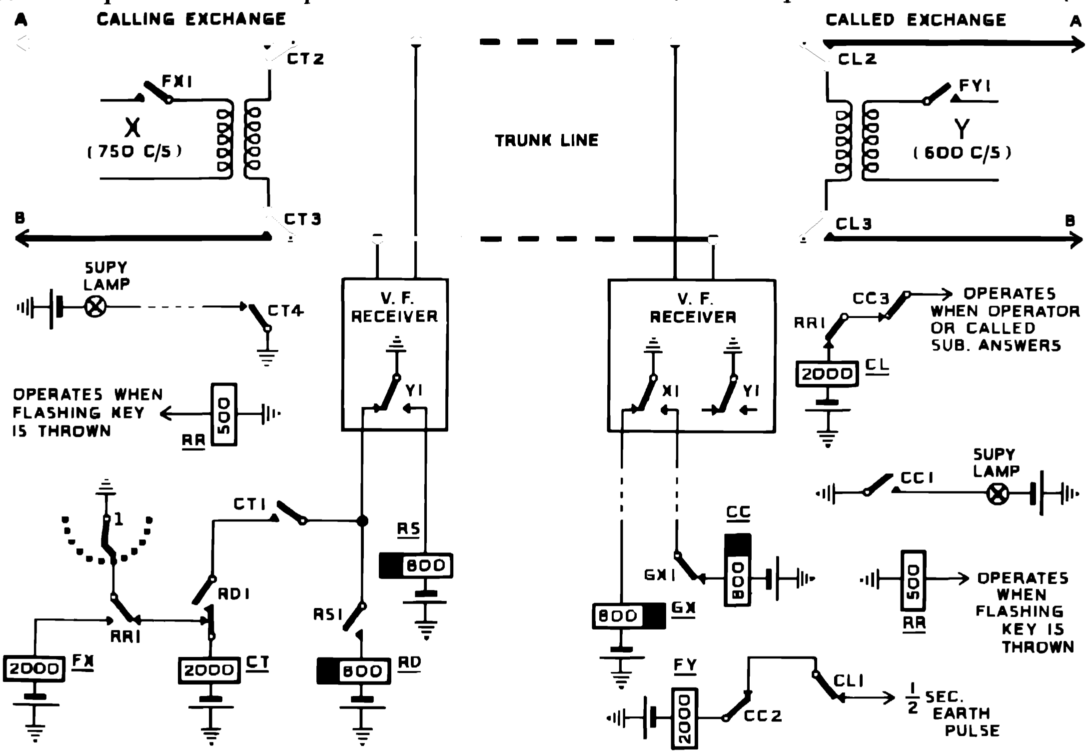


FIG. 395. SUPERVISION AND FLASHING
(2 V.F. Signalling)

the circuit to the speaking conditions as described above.

If at any time during the progress of the call the originating operator wishes to flash the incoming operator, relay *RR* is operated from the position flashing key. ***RR*1** disconnects *CT* and applies earth from arc 1 of the uniselector to energize *FX*. ***FX*1** now applies X-tone to line for so long as the flashing key is operated. At the incoming end of the circuit the operation of *X*1 (in the V.F. receiver) first releases *GX* and, when *GX*1 is fully restored, energizes relay *CC*. ***CC*1** lights the answering cord supervisory lamp on the incoming position whilst ***CC*2** and ***CC*3** disconnect the circuits of relays *FY* and *CL* so that the X-tone is not transmitted to the called subscriber.

Flashing in the reverse direction is obtained in a similar manner. The operation of the flashing key

the operation of *CC* to a short false pulse of X-tone.

Release Conditions. At the end of the call the operator at the outgoing end of the circuit withdraws her plug from the outgoing multiple jack and thereby releases relay *M* (Fig. 396). *M2* now provides a circuit to drive the uniselector from switch to the signalling condition. A continuous Y-tone is now returned to the originating exchange for so long as the plug remains in the incoming jack. When the plug is finally removed, *S* releases and in turn releases relays *CR* and *FY* to restore the circuit to normal. At the outgoing end of the circuit, the continuous Y-tone operates relay *RS*

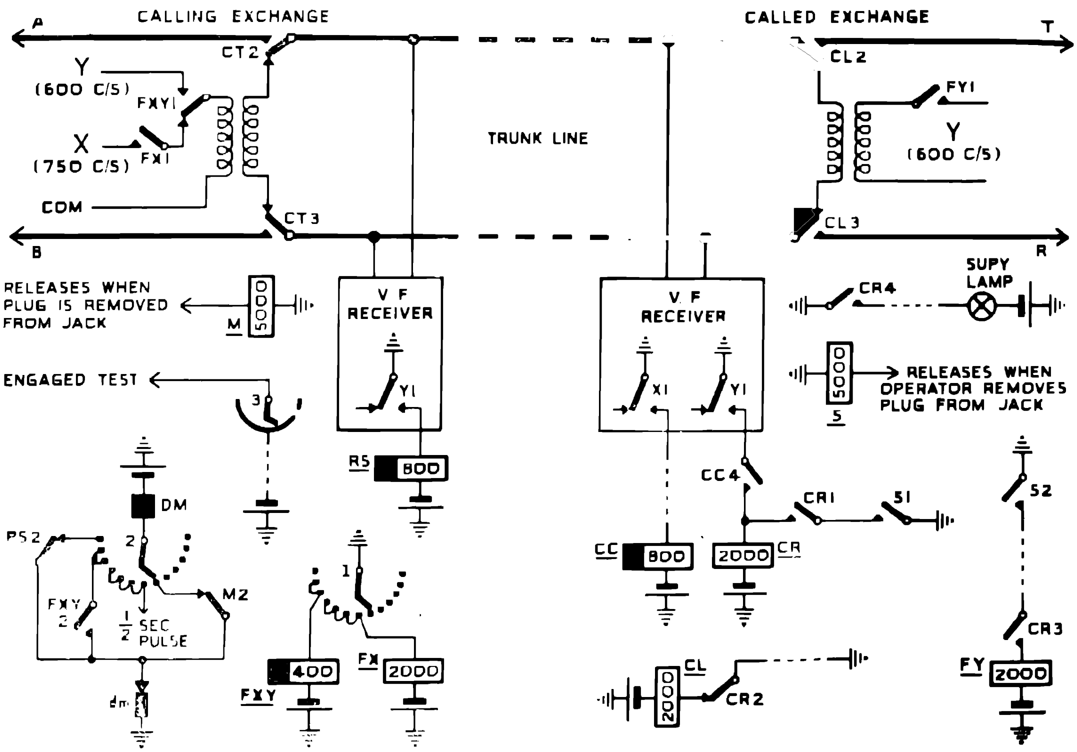


Fig. 396. Release Conditions
(2 V.F. Signalling)

position 5, and the mechanism continues to step under the control of half-second earth pulses. Whilst the wipers are passing over positions 6–9, relay *FX* is operated and at **FX1** a long pulse of X-tone is sent out to line. When the wipers move from the ninth to the tenth position *FX* is released and *FXY* is operated on the tenth and eleventh contacts, thereby giving a short pulse of Y-tone immediately following the X-tone. At the incoming end of the circuit, the operation of **X1** in the V.F. receiver energizes relay *CC* which at **CC4** prepares the circuit for relay *CR* in anticipation of the short final pulse of Y-tone. When *Y* operates, relay *CR* is energized and is held via **CR1**. **CR4** lights the supervisory lamp, whilst **CR3** completes the circuit for the *FY* relay. **CR2** breaks the circuit of *CL* to disconnect the speaking condition and to which at **RS2** prevents the complete homing of the control uniselector until such time as the **Y**-tone ceases. The engaged test condition is maintained from the homing arc of the control uniselector (arc 3) so that the circuit is not freed at the outgoing end until the **Y**-tone has ceased and relay *RS* has restored.

Loop Dialling. The elementary principles employed when an automatic subscriber dials a number have already been considered in Chapter VIII. The same principle of loop impulsing can be adopted from a manual exchange on calls to nearby automatic subscribers. Arrangements are provided whereby the dial on the operator's position can be associated with the junction by means of a dial key or a dialling plug. The operation of the dial key completes the loop circuit to the

distant automatic exchange through the impulse springs of the dial (Fig. 397). Relay *A* at the distant exchange operates and during dialling, the disconnexion of the loop at the dial impulse contacts allows relay *A* to release during the break period of each impulse. The contact of relay *A* in turn controls the stepping circuit of the automatic selector.

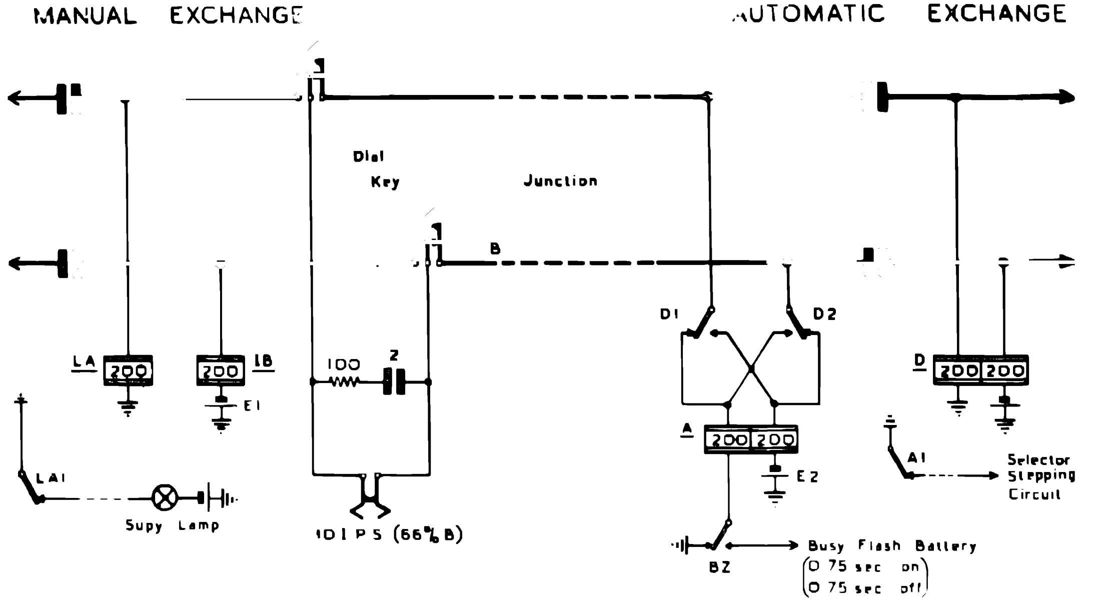


FIG. 397. PRINCIPLE OF LOOP DIALLING OVER JUNCTIONS

The limiting factors for loop dialling over junctions are determined by the line resistance and capacitance which produce distortion of the impulses. If this distortion is excessive, then erratic operation of the selector occurs. This problem is considered in some detail in Volume II. There is, however, often an artificial limitation to the junction limits for loop dialling due to the presence of the transmission bridge at the outgoing exchange. In Fig. 397, *LA* and *IB* represent the calling cord impedance elements of a Stone type transmission bridge. When at the end of impulsing the dial key is restored, the *A*-relay at the distant automatic exchange is held over the *B*-wire by the current resulting from the *difference* in voltage of the automatic exchange battery (*E*2) and the manual exchange battery (*E*1). If the line resistance is such as to produce insufficient holding current under these conditions, then simple loop impulsing cannot be employed. It should be noted that when the called subscriber replies, relay *D* operates and at *D*1 and *D*2 reverses the connexion of the *A*-relay coils to line. The *A*-relay is therefore held *after* the called subscriber has answered by the current in one winding from *E*2 to the earth at *LA*, and in the other winding from the battery at *E*1 to the earth on the second coil of relay *A*. The critical condition is between the time when the dial key is restored and the time when the called subscriber answers. For these reasons loop dialling is not practicable from a 40 V exchange (where there is only an effective p.d. of 50 V − 40 V = 10 V for the holding condition), and is limited to circuits of less than 350 Ω loop resistance when the manual exchange is 22 V. Loop dialling is generally unsatisfactory from exchanges of the C.B.S. type due to the high resistance of the cord circuit elements and, with primary battery installations, due to the wide range of voltage of the primary battery.

When loop impulsing is restricted due to the holding condition, it is necessary to resort either to battery dialling or to provide a transmission bridge in the outgoing circuit at the manual exchange which will effectively isolate the d.c. conditions of the cord circuit from the line. An example of the latter arrangement is given in Chapter XVII, but in the past the usual course has been to adopt battery dialling.

Precautions are necessary in a loop dialling system to prevent the transmission of a false impulse to the automatic exchange whilst the circuit is being switched for dialling at the manual exchange. A false impulse may in particular occur

uring the insertion of the calling plug into the utgoing jack. The tip of the plug momentarily oops both springs of the jack and this loop is then ollowed by a short break period during the further nsertion of the plug. A second possible source of false impulsing is at the ringing or dial key contacts which must establish the loop circuit of the dial before disconnecting the holding conditions of the cord circuit. Usually, a false impulse suppression circuit is provided which overcomes the momentary break during the insertion of the plug and avoids the use of make-before-break key contacts.

Before leaving Fig. 397 it is of interest to note how the busy flash signal is returned to the manual exchange if the required automatic subscriber is engaged. If the called line tests busy, contact *BZ* operates and applies an intermittent busy flash battery to the positive or *A*-wire of the junction. The busy flash battery is applied for 0·75 sec every 1·5 sec, and by pulsing relay *LA* at the manual exchange causes the calling cord supervisory lamp to flash in a manner similar to the busy tone transmitted over the speaking pair.

Battery Dialling. The resistance and capacitance to earth of an external line are directly proportional to the length of the line. Impulse distortion can therefore be reduced by impulsing over one wire only instead of over the loop circuit already considered. The impulses must, of course, be converted from the battery or earth pulses along one wire of the line to loop impulses at the selector. This necessitates an impulse conversion relay set at the automatic exchange. It should be noted that the introduction of this relay set also provides a point for the separation of the automatic selector circuit and the manual exchange cord circuit after dialling has been completed. It is for this reason that impulsing over one wire is often adopted when loop impulsing is prevented not by impulse distortion considerations but by the holding conditions enumerated above.

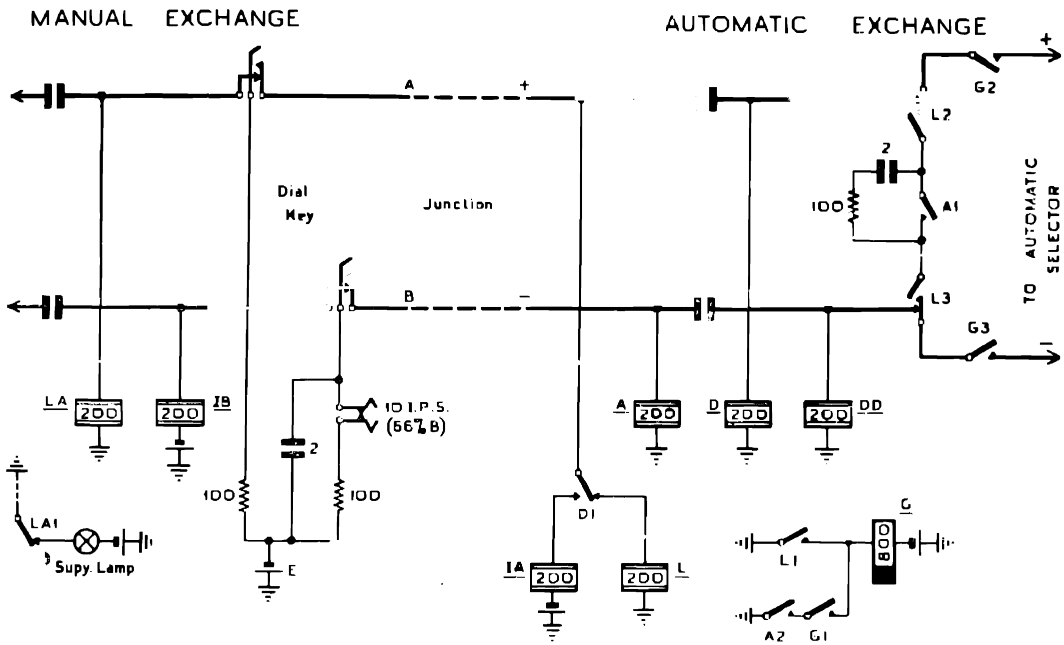


FIG. 398. PRINCIPLE OF BATTERY DIALLING OVER JUNCTIONS

Fig. 398 shows the basic elements of a battery dialling circuit in which the impulses are in the form of interruptions of current in the *B*-wire from a dialling battery at the manual exchange. When the dial key is operated, battery is applied to the *A*-wire via a 100 Ω limiting resistance to operate relay *L* at the automatic exchange. Battery is similarly sent out via the dial impulse contacts to the *B*-wire and thence to operate relay *A* at the automatic exchange. Relay *L* prepares the impulsing loop at **L2** and **L3**. **L1** operates the slow-to-release relay *G* which at **G1** and **G2** further prepares the impulsing loop to the automatic selector. **A1** completes this loop. During dialling *A* releases at each break period and repeats the impulse to the automatic selector at *A*1. The circuit is so arranged that relays *A*, *L*, and *G* must all be operated before

the automatic selector is seized. By this arrangement any momentary interruption of the circuit when the calling plug is being inserted into the outgoing jack cannot produce a false impulse to the automatic selector. A false impulse suppression circuit is therefore unnecessary with battery dialling.

At the termination of impulsing, the dial key is restored and relay *A* is held from the battery on the *B*-wire from the cord circuit at *IB*. Relay *L* releases due to the absence of battery on the *A*-wire of the cord circuit and at *L2* and *L3* switches through the circuit for conversation. When the called party replies, relay *D* operates from battery over the positive wire from the automatic selector, and at *D1* returns battery on the *A*-wire to operate the supervisory relay *L A* in the cord circuit at the outgoing exchange.

Both loop and battery dialling are not satisfactory on two-wire repeatered circuits owing to the necessity of coupling together the two sections of line on each side of every amplifier. Loop dialling produces no undue transmission difficulties on four-wire amplified circuits, but the condensers in the 4-2 wire terminations cause considerable impulse distortion which seriously limits the length of line over which battery dialling is satisfactory. The distortion is not so pronounced when loop dialling is adopted on four-wire circuits. Possibly the greatest disability of battery dialling is the amount of interference introduced on neighbouring conductors in the same cable. With loop dialling the magnetic field due to the growth or decay of current in one conductor is substantially neutralized by the opposite current in the second conductor. With battery dialling or with any form of impulsing over one wire only, there is no such neutralizing effect and during impulsing the sharp rise and fall of the magnetic field cuts the adjacent conductors and induces in them a disturbing e.m.f. Generally speaking, if there are no limitations due to the holding conditions, loop dialling can be adopted over junctions of up to 1500 Ω loop resistance. If it is desired to dial over two or three junctions in tandem, then the distortion produced limits the resistance of each junction in the chain of links to approximately 800 Ω (loop resistance). The dialling limits for battery dialling are largely dependent upon the voltage of the dialling battery. Very approximately, battery dialling can be adopted on junction lines of up to 2500 Ω loop resistance when the voltage of the dialling battery is 50 V.

Impulse Regeneration. It has already been stated that the use of loop or battery dialling is limited by the degree of impulse distortion resulting from the primary constants of the line. The range of dialling can be increased almost indefinitely by the insertion at suitable points of apparatus which will, on receipt of a distorted impulse train, send out a similar train of undistorted impulses. The apparatus may consist of a network of condensers and inductors so arranged that they apply to an incoming impulse a distortion which is equal and opposite to that produced by the line. Such a unit might be termed an *impulse correcting circuit* and in certain circumstances it is of value. It has, however, certain limitations such as the necessity for individual adjustment on every line, and it is not easy to cater for the comparatively wide limits of impulse ratio obtained in practice. It should be noted that impulse correcting devices cannot possible rectify irregularities of impulse frequency. An alternative method of dialling over long distances, and the one which has been adopted for use within the toll area of an exchange, is to use the incoming distorted impulses to control an impulse sending device which is capable of re-transmitting a new train of undistorted impulses. The process is termed *impulse regeneration* and the apparatus is known as an *impulse regenerator*. Whilst the impulse regenerator can, of course, be largely electrical in operation, it has been found that a more mechanical device requires less space and is less expensive than a complex electrical circuit. The mechanical impulse regenerator is considered in detail in Volume II, but in principle it is somewhat similar to a dial mechanism with an electromagnet energized by the incoming impulses. The electromagnet steps the mechanism and winds up the main driving spring. On completion of an incoming impulse train the spring is allowed to unwind and a pair of impulse contacts sends out the number of impulses corresponding to the received train.

Long Distance D.C. Impulsing. The adoption of impulse regeneration does, of course, require that a suitable point should be available at regular intervals for the insertion of regenerators. On the longer circuits this is not always convenient. Moreover, regeneration is not suitable for distances above a certain limit on account of the steadily increasing cost and the time lag introduced by numerous repetitions. In America and in some Continental countries, low frequency a.c. dialling, using frequencies in the order of 17 to 50 c/s, has been used successfully on long circuits. The attenuation of ordinary underground cables is very high at these low frequencies and is generally prohibitive on loaded cables.

In this country a system of d.c. impulsing has been designed which will work satisfactorily on

ines of up to 100 miles in length provided that a d.c. signalling path is available. The principle of this method is illustrated in Fig. 399. Battery and earth via suitable resistances are connected to the A- and B-wires of the trunk circuit. In the normal condition, however, the two wires are connected together by the impulse contacts and no current flows to line.

When the impulse springs open for the first impulse, the short circuit is removed and current

108 Ω coil to provide a safe holding circuit for *PR* after the termination of the pulse.

When the dial springs close at the end of the impulse, the voltage surge in the transformer secondary is in the opposite direction, i.e. it allows a momentary increase of current in the anode circuit. The values are so adjusted that the higher current in the 1600 Ω winding of *PR* overcomes the effect of the augmented current in the 108 Ω winding and *PR* releases. *HSA* re-operates to

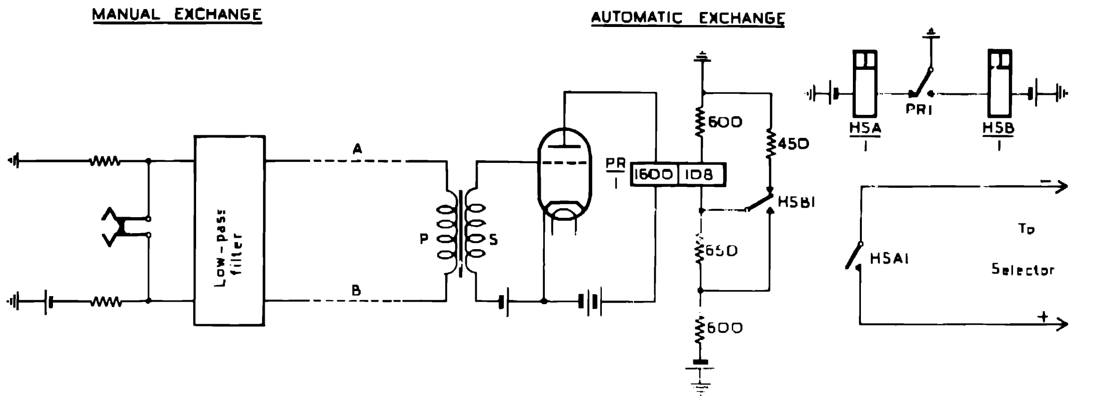


FIG. 399. PRINCIPLE OF LONG DISTANCE D.C. IMPULSING

flows round the loop until the springs reclose at the end of the impulse. At the incoming end of the circuit, the line is terminated by a transformer and the current in the primary winding during impulsing is shown as in Fig. 400. Corresponding e.m.f.s are induced into the secondary winding at each *change* of current in the primary—the secondary surges being in alternate directions as the current in the primary rises and falls. The surges of e.m.f. are applied to the grid of an amplifying valve which contains a polarized relay in its anode circuit. The windings of the polarized relay are so connected that the current in the 1600 Ω winding tends to release whilst that in the 108 Ω winding tends to operate the relay. The valve is biased as for an ordinary amplifier, and in the quiescent condition the anode current is sufficient to release *PR* against the effect of the 108 Ω coil. *HSA* is therefore energized and its contact ***HSA*1** loops the − and + selector wires. When the dial springs open, the voltage surge impressed on the grid of the valve is in such a direction as to increase the negative bias, i.e. it momentarily reduces the anode current. Relay *PR* now operates from the current in the 108 Ω winding and at ***PR*1** releases *HSA* and energizes *HSB*. *HSA*1 repeats the impulse to the selector whilst ***HSB*1** increases the current in the

terminate the impulse to the selector and *HSB* restores (at *HSB*1) the current in the 108 Ω winding to its original value.

The theory of the differentiated impulse system utilized in long distance d.c. dialling is somewhat involved, and it is sufficient at this stage to consider the basic principles on which the system is designed. With ordinary loop dialling (Fig. 397) the line conductors are disconnected during the break period of each impulse and hence the whole of the charge held by the line capacitance flows through the impulsing relay to prolong its operation. This results in a shortening of the break impulse at the relay contacts and is the main cause of impulse distortion on long lines. In long distance d.c. impulsing the conditions are materially improved by providing a path at the sending end which will absorb a portion of the charge stored in the line to line and in the line to earth capacitance. With such an arrangement the current at the receiving point collapses much more quickly, and for a given degree of impulse distortion it is possible to dial over appreciably longer lines. The shape of the received impulse wave does, however, still depend upon the characteristics of the line and, with normal loop impulsing, individual relay adjustments are necessary for each length of line if distortion is to

be avoided. Such individual adjustments are undesirable and can be avoided only if a means can be devised of increasing the rate of current change applied to the receiving relay. A possible solution lies in the fact that, in the receiving relay circuit, the maximum *rate of change of current*, i.e. the steepest slope of the current-time curve, occurs

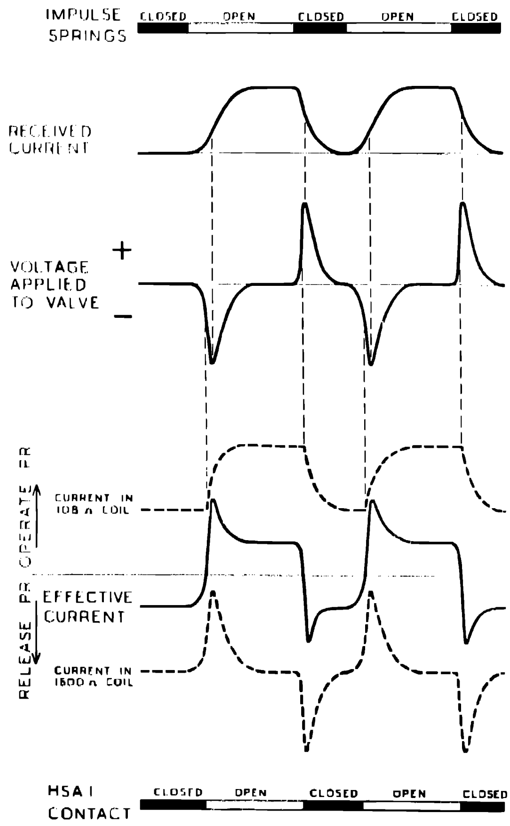


FIG. 400. CURRENT IN LINE AND IMPULSING RELAY
(Long distance D.C. Impulsing)

shortly after the current commences to change. (See Fig. 119.)

The e.m.f. induced in the secondary winding of a transformer is greatest when the rate of current change in the primary is a maximum. Moreover, the direction of the e.m.f. is dependent upon whether the current in the primary is rising or falling. In the differentiated impulse system, the value of the current in the 1600 Ω winding is determined by the voltage on the grid of the valve, which in turn depends upon the *rate of change* of the current in the line. By the adoption of this principle, operating and release currents with a steep rate of growth and decay are applied to the impulsing relay. The slope of these current pulses is substantially independent of the length of line. It is apparent that as the operating and release pulses occur only at the beginning and end of each impulse, means must be provided to hold the relay between pulses (the *HSB*1 contact). A further feature of long distance d.c. impulsing is the abolition of the highly inductive impulsing relay in the line circuit. This improves the rate of current rise at the received end of the circuit, but necessitates a pre-dialling signal to change over from the speaking to the signalling conditions.

It will be noted that the current surges in the secondary circuit at both the beginning and end of a break impulse are similar in shape. It is this similarity which avoids a large portion of the distortion experienced with normal impulsing. The introduction of the repeating relays *HSA* and *HSB* provides a possible source of impulse distortion, but this is minimized by the use of high-speed relays of the Siemens type. The low-pass filter at the outgoing end of the circuit is introduced to limit the initial surge into the line capacitance.

2 V.F. Dialling. It has already been stated that the longer trunk circuits are being rapidly converted to carrier working where the physical line conductors are shared by a number of speech channels. It is therefore not possible to employ d.c. dialling methods on the longer trunk circuits.

A development of the 2 V.F. signalling scheme has been introduced in the last few years to provide direct dialling facilities on a voice-frequency signalling basis over the zone to zone links. Since most zone centres are also the automanual switchboards of large automatic areas, 2 V.F. dialling provides a means whereby any trunk operator can dial direct any automatic subscriber in the vicinity of any other zone centre exchange. 2 V.F. dialling has therefore substantially superseded the 2 V.F. automatic signalling scheme already described.

The signal tones (750 c/s and 600 c/s) which are used on the 2 V.F. signalling scheme are retained in the 2 V.F. dialling scheme. The V.F. receivers are, in fact, identical in both schemes. There are, however, certain differences in the signal combinations to cater for the dialling facility. The calling condition when an operator inserts a plug into an outgoing circuit is, as before, a short pulse of X-tone. This tone prepares the equipment at the incoming end of the circuit to receive the impulse trains but, unlike the 2 V.F. signalling scheme, no Y-tone is returned to the originating exchange at this stage. The operator dials the number in the usual way and a pulse of X-tone is sent out for each break impulse of the dial, i.e. the line impulses

consist of trains of X-frequency of 66 msec duration with a 33 msec period of no tone between impulses. When the called subscriber answers, a short single pulse of Y-tone is returned from the distant exchange to darken the supervisory lamp at the originating manual board. Similarly, when the called subscriber clears, a chain of short Y-pulses is returned to the manual exchange as in 2 V.F. signalling. The clear down signal is, as before, a long pulse of X-tone followed immediately by a short pulse of Y-tone. The circuit is so arranged that the outgoing multiple is held engaged for a period sufficient to allow all the various relays at the incoming and outgoing terminations to restore. The flashing facility is not provided on 2 V.F. dialling.

Calling and Dialling. The circuit elements of a 2 V.F. dialling circuit during the establishment of a call are illustrated in Fig. 401. Relay *M* operates when the plug is inserted into an outgoing multiple jack and, as described previously, *M1* causes the control uniselector to step from its home contact. Relay *FXY* is operated whilst the uniselector steps over contacts 1 and 2 and at *FXY1* sends a 100 msec pulse of X-frequency to line. At the incoming end of the circuit the operation of *X1* in the V.F. receiver operates relay *L* which locks. At the termination of the initial X-pulse the release of *X1* now energizes relay *AR* via contact *L1*. *AR1* prepares the impulsing circuit to the automatic selector and relay *IL* now operates over the negative wire to the battery at the impulsing relay of the selector. *IL1* in turn operates *NN* and *NN1* prepares the circuit for relay *C*.

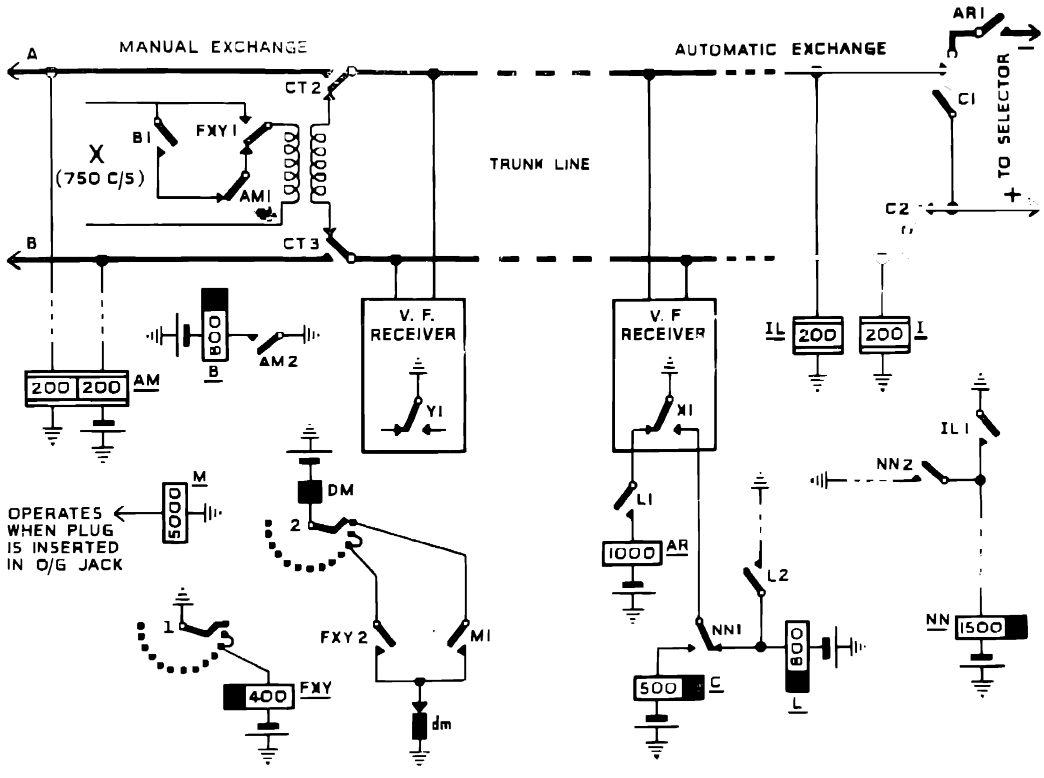


FIG. 401. CALLING AND DIALLING
(2 V.F. System)

When the dial key is thrown at the outgoing exchange relay *AM* operates and at *AM2* energizes relay *B*. *AM* responds to the break impulses from the operator's dial and at each release of *AM*1, X-tone is sent out to line via *B1*, *AM*1 and *FXY*1. Relay *B* has an appreciable release lag and holds during the impulse trains. At the incoming end of the circuit the operation of *X1* in the V.F. receiver releases *AR* for 66 msec during each pulse of X-current on the line. *X1* also energizes relay *C* on receipt of the first impulse and *C1* completes the impulsing loop to the automatic selector. Relay

C holds due to its slow to release feature during impulsing, but at the end of the impulse train *C1* releases to switch through the speaking pair so that the operator at the outgoing end can hear any tones received during the setting up of the call. There is, incidentally, an arrangement (not shown in Fig. 401) at the outgoing end to by-pass the *CT2* and *CT3* contacts for these tones.

relay *L* whilst *L4* releases *PY*. Relay *PY* is slow to release and hence a circuit is completed for relay *FY* between the restoration of *L4* and the release of contact ***PY1***. At the same time relay *CL* is energized from the earth at ***FY2*** via ***PY2*** until relay *PY* releases. During this period, contacts ***CL2***, ***CL3*** and ***FY1*** give a short pulse of some 200 msec of Y-tone to line.

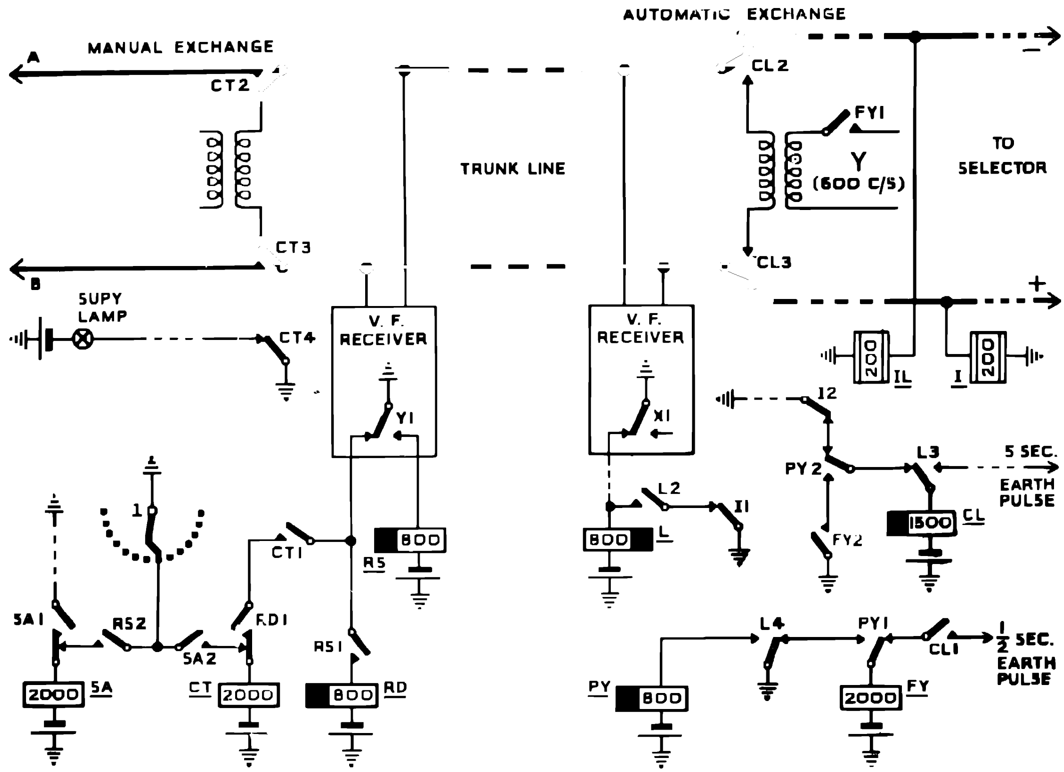


Fig. 402. Answering Conditions
(2 V.F. Dialling)

It has already been stated that any continuous tone would prevent the passage of a signal in the opposite direction due to the presence of echo suppressors on the line. If, therefore the Number Unobtainable Tone (400 c/s continous) is encountered in the setting up of a call, means must be provided to interrupt the tone periodically in order to permit the passage of a clearing signal. The circuit is arranged so that relay *CL* (Fig. 402) is operated for 1 sec every 5 sec prior to the subscriber answering. ***CL2*** and ***CL3*** interrupt the speaking pair.

Answering Condition. When the called subscriber answers, the current in the loop to the automatic selector is reversed. Relay *IL* releases and relay *I* is now operated (Fig. 402). ***I1*** releases

At the outgoing end of the circuit the operation of ***Y1*** in the 2 V.F. receiver energizes relay *RS*. ***RS2*** completes a circuit for the operation of relay *SA* from the earth on the control uniselector arc 1. *SA* locks and at ***SA2*** completes the circuit for relay *CT*. ***CT2*** and ***CT3*** switch through the lines to the speaking condition, whilst ***CT4*** darkens the supervisory lamp in the cord circuit.

When the called subscriber replaces his receiver, the line reversal from the selector is restored, thereby allowing relay *IL* to re-operate and relay *I* to release. The restoration of *I2* provides an operate circuit for relay *CL* which switches to the signalling condition at ***CL2*** and ***CL3***. ***CL1*** applies a half-second earth pulse to relay *FY* so that contact ***FY1*** now sends out a continuous train of

half-second Y-pulses to line. At the manual exchange, receipt of the first Y-pulse operates relay *RS* and, at the first break, relay *RD* is operated. ***RD*1** now extends the holding circuit for *CT* via ***CT*1** to the earth at *Y*1. The next pulse of Y-tone breaks this holding circuit and relay *CT* releases to light the cord circuit supervisory lamp at *CT*4 and to disconnect the speaking pair at *CT*2 and *CT*3. the incoming termination. The circuit is so designed that the pulses of Y-frequency continue until the circuit is substantially restored at the incoming end. A further guard is provided at the outgoing end of the circuit by ***RS*3** which does not complete the homing circuit of the uniselector until after the Y-pulses have ceased to arrive.

Voice-operated Signalling Unit. Circumstances

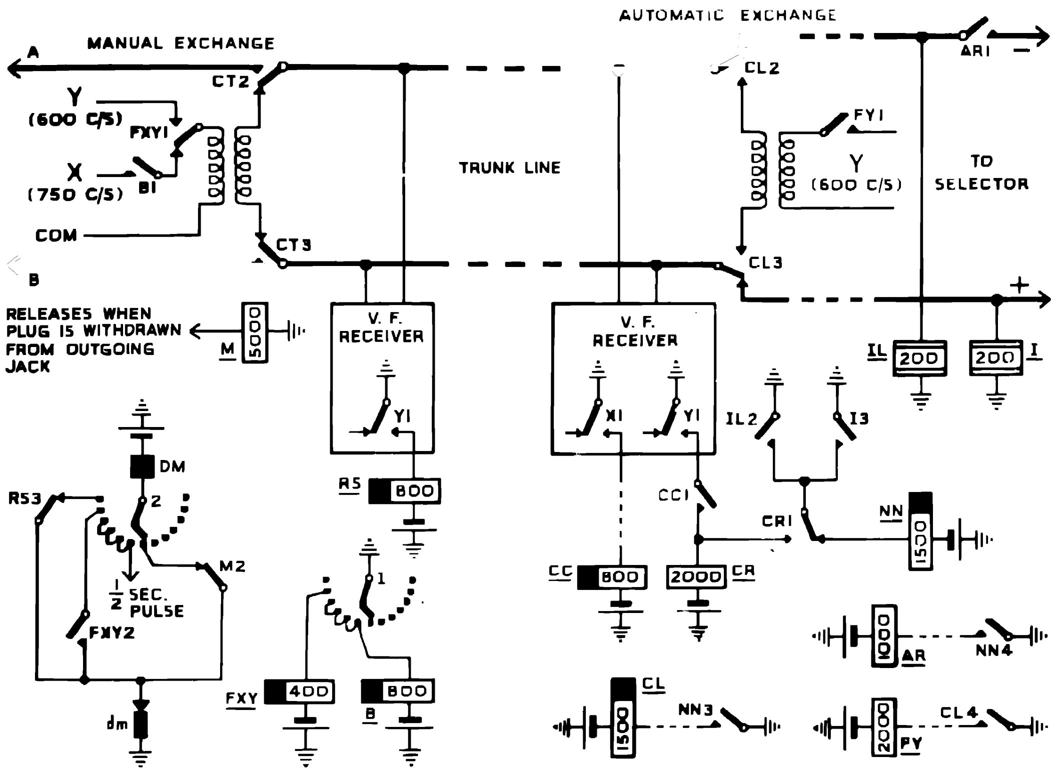


Fig. 403. Release Conditions
(2 V.F. Dialling)

Release Conditions. Relay *M* (Fig. 403) releases when the outgoing operator withdraws her plug from the jack. *M*2 completes the stepping circuit for the control uniselector which continues to drive under the control of half-second earth pulses. During this period relay *B* is operated from arc 1 for a period from 2 to 6 sec and at ***B*1** sends out X-frequency to line. This is followed immediately by the operation of *FXY* which at ***FXY*1** sends out a short terminating pulse of Y-frequency. At the incoming end of the circuit the X-pulse operates relay *CC* which at **CC1** prepares the circuit for the operation of relay *CR* when the Y-pulse is received. In due course *CR* operates and locks at ***CR*1**. Relay *NN* is now disconnected and contacts of *NN* in turn release all the remaining relays at occasionally arise (especially under war conditions) when a long distance circuit is required urgently and the line composition or available apparatus do not permit the use of any of the usual signalling methods. A voice-operated relay device (abbreviated V.O.R.) has been designed to give a simple calling signal when speech at normal levels is transmitted over the circuit. The V.O.R. consists of a two-valve unit with three relays and a signal lamp. The power supply can be either batteries or the ordinary a.c. mains.

The V.O.R. is connected directly across the speaking pair and is designed to introduce a minimum tapping loss. The incoming speech signals are passed via an input transformer to the first valve which operates as an amplifier and voltage

limiter, i.e. the signal passed to the second valve is limited to a predetermined maximum value. The second valve is a rectified-reaction stage with a signalling relay in the anode circuit. The relay operates on receipt of a speech signal and releases a relief relay to give a continuous signal on the calling lamp. The unit is arranged to operate at conditions can be provided by one or two unit combinations of four signals. If the four signals are designated *w*, *x*, *y*, and *z*, then the necessary differentiation for each digit can be set up by the combinations given in the table at the foot of this page.

The four conditions can, if desired, be d.c. signals

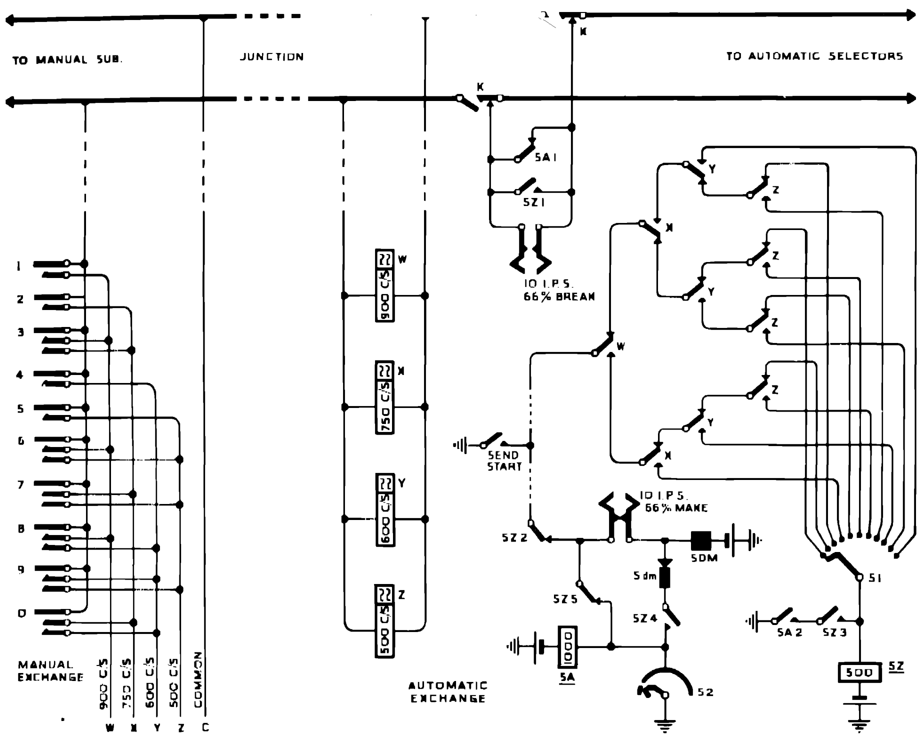


Fig. 404. Elements of V.F. Keysending

any received frequency between 350 and 4000 c/s, and has a maximum sensitivity around 1000 c/s where it will operate with a signal level as low as 30 db below 1 mW.

An operating delay of from 100 to 350 msec is provided by the rectified-reaction stage and the relief relays. This delay is necessary to prevent false operation to momentary surge currents in the line.

Keysending. As explained previously, keysending is a method of rapidly establishing connexions through an automatic exchange by the consecutive depression of digit keys. With this method of working it is necessary to convert from the conditions set up by the digit keys to give the required number of break impulses to step the automatic switches. Ten different conditions are required to provide for the digits 1, 2, 3 . . .0. These ten on four wires (as in keysender *B*-position working) or they can be four seperate frequencies forwarded over the speaking pair of the junction. The principle of conversion to break impulses is the same in each case, but the voice frequency keysending system is assumed in Fig. 404.

At the keysending point (usually a manual exchange) a strip of ten digit keys enables combinations of four frequencies (W, X, Y, and Z) to

Digit	Combination	Digit	Combination
1	w	6	$w + z$
2	x	7	$x + z$
3	$w + x$	8	$w + y$
4	y	9	$y + z$
5	z	0	$x + y$

be sent out to line in accordance with the foregoing tabulation. At the automatic exchange four relays (*W*, *X*, *Y*, and *Z*) are connected to the line to receive these frequencies. With voice-frequency working, the relays may be of the mechanically tuned type or they may be ordinary relays connected to a valve amplifier with an electrical acceptor circuit for each frequency. Contacts of the *W*, *X*, *Y*, and *Z* relays are arranged to mark a particular contact of a uniselector type *send switch* (*S*1). When the equipment is ready for sending out break impulses to the automatic selectors, the "Send Start" contact closes to apply an earth to a particular contact of the *S*1 bank depending upon the combination set up. At the same time an earth is applied to the send switch driving magnet via impulse machine contacts. These contacts give an impulse frequency of 10 i.p.s. with a 66 per cent make period. Relay *SA* also operates when the send start condition is established. Contact ***SA*1** removes the short circuit from a second set of impulse springs which are connected to the — and + wires of the first automatic selector. The line impulse springs are also 10 i.p.s., but with the usual 66 per cent break ratio. Impulses are sent out to step the automatic selector until such time as the *S*1 wiper reaches the marked contact. It will be noted that since both sets of impulse springs are synchronized the appropriate number of break impulses will have been sent out by the time that the *S*1 wiper reaches the marked contact. Relay *SZ* now operates to the send start earth and locks via contacts ***SA*2** and ***SZ*3**. ***SZ*1** short-circuits the line impulse springs to prevent further stepping of the selector, whilst ***SZ*2** breaks the drive circuit of the send switch. ***SZ*4** now completes a homing circuit for the send switch driving magnet from the earth at *S*2 via the send switch interrupter contacts (*Sdm*). The send switch now homes in readiness for the next digit and when the wipers reach the first contact relay *SA* releases due to the removal of earth at *S*2. *SA*1 now takes over the function of ***SZ*1** in preparation for the release of *SZ* by contact *SA*2.

The apparatus which carries out the conversion from combinations of four signals to break impulses is known generally as a *sender*. The detailed circuit of the sender is very complex since storage relays must be provided for each digit before transmission of break impulses is commenced. There are, moreover, a number of circuit refinements to ensure that contact *SA*1 does not operate except when the line impulse springs are closed. Similarly contact *SZ*1 must be arranged to close during the make period of the impulse springs. It should perhaps be mentioned in passing that in addition to the digits 1 to 0, a start signal is required on V.F. keysender circuits to prepare the equipment for reception of the frequency combinations and to cancel out any false operation of the receiving relays due to speech-frequency signals.

C.C.I. Signalling. The C.C.I. system as described in Chapter XII provides a means whereby impulse trains dialled by an automatic subscriber are converted to lamp signals on a display panel at a nearby manual exchange. The system of signalling adopted in C.C.I. working is of interest in that it shows how impulses may be coded for transmission by d.c. signalling methods over a two-wire junction. The system of coding was designed primarily to give a more rapid speed of transmission than is obtainable when ordinary break-and-make impulses are used. The system also requires a minimum of apparatus at the manual exchange.

The principle of C.C.I. signalling is illustrated in Fig. 405. The line signals are of three types:

Light positive—an earth sent out over the positive wire from the automatic exchange and a 5000 Ω battery on the negative wire.

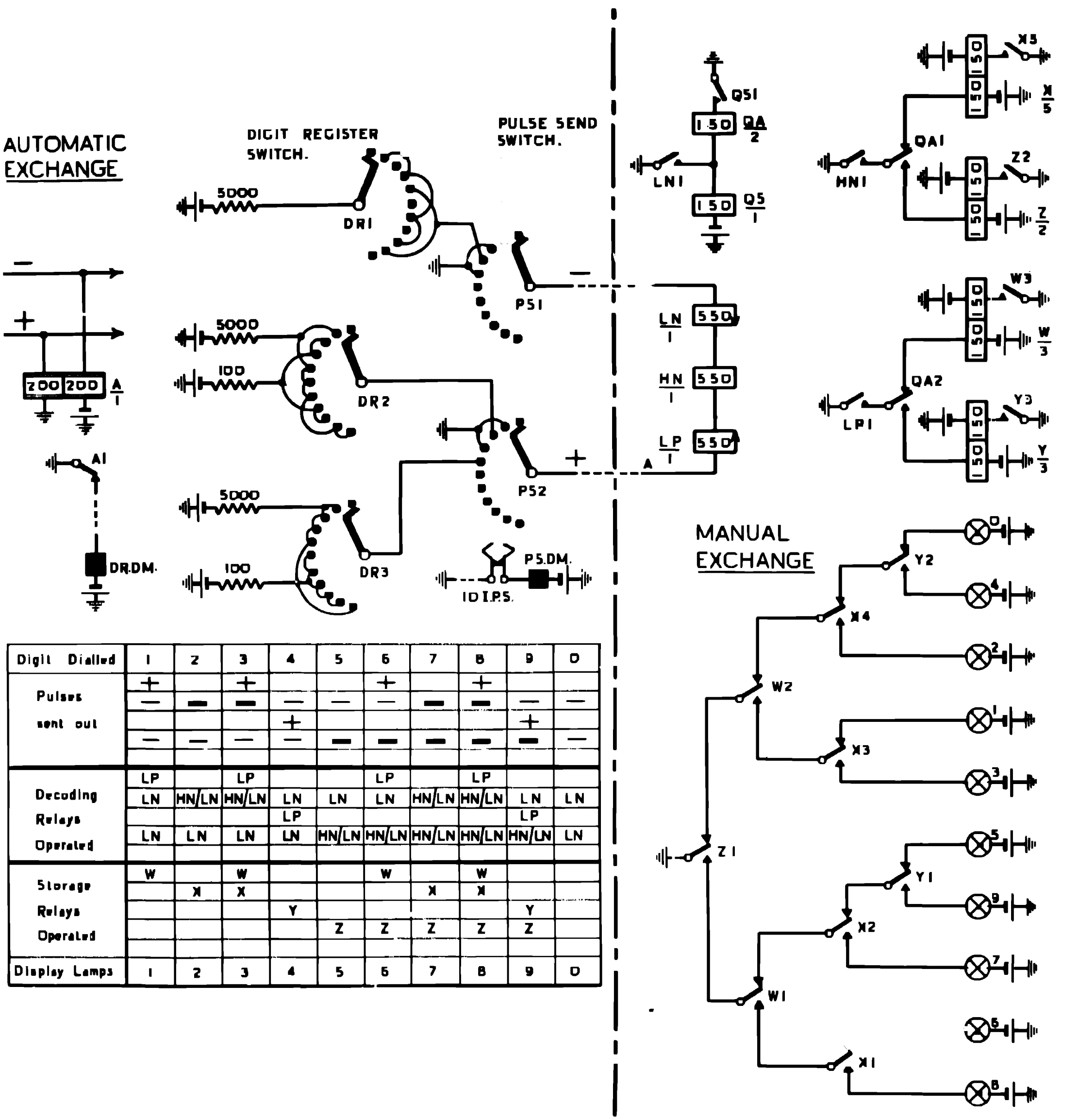
Light negative—a reversal of the above conditions, i.e. earth sent out on the negative wire from the automatic exchange with a 5000 Ω return battery on the positive wire.

Heavy negative—a full battery on the positive wire returning to a full earth on the negative line at the automatic exchange.

Each digit is transmitted whilst a pulse send switch moves over four consecutive contacts of its bank. For example, the digit 1 is transmitted by a light positive pulse, a light negative pulse, no pulse and a second light negative pulse in rapid succession. Digit 6, on the other hand, consists of a light positive pulse, a light negative pulse, no pulse, and finally a heavy negative pulse. The pulse send switch was originally designed to rotate at 20 steps per second, which gave a transmission time of 0·8 sec for a four-digit number. The drive speed of the pulse send switch has now been reduced to 10 i.p.s. to obtain a more reliable operation of the receiving relays, so that the sending time for a four-digit number is now 1·6 sec—irrespective of the length of the original break impulse trains. The circuit is terminated at the incoming end by three relays in series. Two of these relays are polarized whilst the third is not polarized. One polarized relay (*LP*) operates to a light positive pulse whilst the non-polarized relay (*HN*) operates only when a heavy negative pulse is transmitted. The light negative relay (*LN*) responds to either light or heavy negative pulses but not to the light positive pulse. The contacts of the light positive

and heavy negative relays provide the operate circuit for the storage relays, whilst the operation of the light negative relay is a switching signal to change over the conditions.

has three arcs *DR*1, *DR*2, and *DR*3, which ar strapped and connected to battery and eart potentials as required. The digit receive switc arcs are in turn wired to the pulse send switc



Digit Dialled	1	2	3	4	5	6	7	8	9	0
Pulses sent out	+		+			+		+		
	—	▬	▬	—	—	—	▬	▬	—	—
				+					+	
	—	—	—	—	▬	▬	▬	▬	▬	—
Decoding Relays Operated	LP		LP			LP		LP		
	LN	HN/LN	HN/LN	LN	LN	LN	HN/LN	HN/LN	LN	LN
				LP					LP	
	LN	LN	LN	LN	HN/LN	HN/LN	HN/LN	HN/LN	HN/LN	LN
Storage Relays Operated	W		W			W		W		
		X	X				X	X		
				Y					Y	
					Z	Z	Z	Z	Z	
Display Lamps	1	2	3	4	5	6	7	8	9	0

Fig. 405. Principle of Coded Call Indicator Signalling

The make-and-break impulses are received in a unit known as a *coder* at the automatic exchange. Here the impulses operate and release relay *A* which in turn steps the driving magnet of a digit receiving switch (*DR*). The digit receiving switch

banks so that, when the pulse send switch wipers move over the four contacts associated with a particular digit receiving switch, they encounter the correct electrical conditions as determined by the digit dialled, i.e. by the position of the digit

receive switch wipers. If, for example, digit 6 is received in the coder, the *DR* switch is stepped to the sixth contact where a 5000 Ω battery is applied to the first contact of the *PS*1 arc via the *DR*1 bank. A similar 5000 Ω battery is passed via the *DR*2 wiper to mark the second contact of the pulse send switch (*PS*2), whilst a full battery is returned via *DR*3 to mark the fourth contact of the *PS*2 arc. When all the digits have been received, a start circuit is completed for the pulse send switch which steps under the action of the 10 I.P.S. control springs and thereby sends out light positive, light negative, no signal, and heavy negative pulses to the distant manual exchange. The first light positive pulse operates storage relay *W*, which locks. The succeeding light negative pulse operates relay *LN* which at ***LN*1** operates *QS*. At the end of the pulse, *LN* releases and allows *QA* to operate in series with *QS*. ***QA*1** and ***QA*2** switch over the connexions to the *LP*1 and *HN*1 contacts in readiness for the next current pulses. The final heavy negative pulse operates *HN*, which now energizes relay *Z* in the storage group. When the operator is ready to receive the call, an earth is applied to the *W*, *X*, *Y*, and *Z* chain contacts to light the appropriate lamp. When digit 6 is dialled, lamp No. 6 is operated via ***Z*1**, ***W*1**, and ***X*1**. The pulse combinations and details of the decoding and storage relays operated for various digits are shown in the tabulation.

The practical circuit is, of course, much more complex since provision must be made for the transmission and reception of four digits. It should be noted that the last pulse of each digit is either light or heavy negative and that there are always two negative pulses for each digit. Relay *LN* is therefore operated twice during the transmission of each digit and the second operation is arranged to free the storage group in readiness for the reception of the next digit.

EXERCISES XIII

1. Explain the principles of C.B. signalling over junctions. What are the limiting factors of this method of signalling? Why is C.B. signalling not generally satisfactory on two-wire repeatered circuits?

2. Describe, with the aid of a diagram, a method of d.c. signalling over junction circuits between central battery manual exchanges, suitable for use in cases where the resistance of the junction circuits is too high for the normal method of central battery signalling. (*C. & G. Telephony, Grade III*, 1943.)

3. Metal rectifiers are sometimes placed in series with the signalling relays on junction circuits. Explain the purpose of these rectifiers.

4. Give the circuit elements of a loop calling junction from an automatic exchange to its remote parent exchange. Show how "manual hold" is obtained.

5. Describe a method of "ringing" over a 4-wire trunk circuit in which currents at 500 c/s, interrupted 20 times per second, are employed. Give a circuit diagram of the signalling conversion equipment which is provided between the 4-wire trunk circuit and the 2-wire circuit to the switchboard. (*C. & G. Telephony, Grade III*, 1947.)

6. Explain what is meant by "rectified reaction" and state when it can be used to advantage. Give a simple circuit to show how rectified reaction can be used for the detection of voice-frequency signalling currents.

7. Describe with reference to a schematic diagram the principal features of a two-frequency signalling system designed for working over long trunk lines. Include a description of the arrangements provided in order to obviate false signals due to speech currents having components of the same frequency as those used for signalling. (*C. & G. Telephony, Grade III*, 1939.)

8. Show how on a 2 V.F. signalling circuit the outgoing multiple at the originating exchange is held engaged until the plug is removed from the incoming jack at the distant termination.

9. Explain how the supervisory lamp at the originating exchange is darkened when the called subscriber answers if the call is routed over:

(*a*) a 2 V.F. signalling circuit.

(*b*) a 2 V.F. dialling circuit.

10. Draw a block schematic diagram of the components of a voice-frequency signalling receiver for long trunk lines, to show the sequence of the several circuit elements from the input transformer to the direct current signalling relays. State the meanings of the signals conveyed by the various combinations of voice-frequency currents as they are brought into use on a typical call. (*C. & G. Telephony, Grade III*, 1944.)

11. In the coded call indicator system the coded pulses for the digit 3 are described as light positive, heavy negative, and light negative. Describe the manner in which these pulses are produced at a director exchange and how they are received and stored at the manual exchange. Illustrate your answer with a simplified circuit diagram. (*C. & G. Telephony, Grade III*, 1944.)

CHAPTER XIV

CABLING, WIRING, AND PROTECTION

THE apparatus required in any given exchange is, of course, dependent upon the system of switching employed. The cable and wire used for the interconnexion of the apparatus and the principles involved for providing an orderly and flexible system of cabling are, however, substantially the same for all systems of switching. Moreover, devices are necessary in all exchanges to provide protection to subscribers, exchange staff and the equipment from the dangers of lightning, contacts with power lines, fire, etc. The protective devices are closely associated with the cabling arrangements of an exchange and it is therefore convenient to consider the two together in this chapter.

There are two main sources of danger to telephone plant and telephone users. Firstly there is the danger due to lightning discharges, and secondly there is the possible danger from contacts with (or induction from) electric light and power circuits. In addition, there is the danger of fire from the exchange power supply itself, but fire risks due to failure of the equipment are minimized by careful circuit design and by the proper fusing of the exchange power supply.

Lightning. The theory of lightning discharge is somewhat involved, but for most practical purposes a lightning stroke may be regarded as an electrical discharge of extremely short duration from a negative charged cloud. The average duration of a lightning discharge is in the order of 50 μsec, and the resultant current to earth during this short period may rise up to a value of 100 000 A or more. The current follows a restricted and previously ionized path, and a single flash sometimes consists of a series of separate discharges along this path. The maximum voltage of a lightning stroke is possibly in the order of $2\frac{1}{2}$ million volts. No insulator (even on very high voltage power lines) will withstand this voltage, and hence it is impossible to prevent the flash-over of the discharge to earth. It is important to remember that the rate of voltage change is very great indeed due to the high voltage concerned and the very short time involved. It has been estimated that the rate of voltage rise for a typical surge is in the order of 1000 kV/μsec, and the rate may be considerably greater than this figure. This very steep voltage/time curve contains components of extremely high frequency. It is apparent, therefore, that if any attempt is made to conduct the discharge to earth by artificial means then the path provided must possess an extremely low inductance. It is for this reason that lightning conductors should be run as straight as possible and without sharp bends.

From a telephone line point of view, damage may occur due to the extremely high values of current or to the breakdown of insulation at the point where the discharge leaves the line to earth. It is usual in this country to provide lightning conductors every tenth pole on long overhead routes, and at all points where the line is diverted underground. These precautions tend to reduce the discharge along the line itself. In most cases, subscribers' lines and junctions are diverted underground near the exchange to avoid unsightly and congested overhead routes in the centre of towns. The ordinary paper-core telephone cable has a breakdown voltage in the order of 1·5 kV. The underground cables do, therefore, to some extent prevent any substantial voltages reaching the exchange equipment. On the other hand, it is desirable to design the protective devices to prevent breakdown of underground cables wherever possible.

Power Lines. When telephone lines run in close proximity to high voltage power lines there is a danger to life and to the telephone equipment due to:

(*a*) Direct contact between the power line and the telephone line.

(*b*) High voltages in the telephone line due to electrostatic or electromagnetic induction from the power line.

Very rigid rules are enforced to prevent direct contact between power and telephone lines. The spacing of the lines must be such that there is no possibility of wires falling on or being blown into contact with each other. At crossings either the power or the telephone lines should be placed underground, or alternatively earthed guard wires and insulated conductors may be used. In underground construction strict regulations are enforced to maintain certain minimum distances between power and telephone cables, and where the required minimum separation is not practicable concrete pillars are introduced to minimize any possibility of contact. Nevertheless, in spite of all precautions

in the lay-out and design of the external plant, there is always a risk of contact due to failure of the physical protective arrangements.

Normally a high voltage power line has relatively little external magnetic field, due to the neutralizing effect of the various phase conductors, but under fault conditions where a heavy current passes through one conductor to earth the balance is upset and there is a powerful magnetic field both from the power line itself and more particularly from the resulting earth current. The electromagnetic field embraces any adjacent telephone conductors, and may induce in them a high and dangerous voltage. There are a number of methods of minimizing this danger, such as the introduction of crosses in the telephone wires at frequent intervals (transpositions), the erection above the power conductors of an earth wire which is efficiently earthed at each pole, etc. It is also important that the protective gear on the power system should be efficient and should operate rapidly. It can be shown that the induced voltage in a telephone line due to an earth fault on an adjacent power line varies inversely with the seperating distance of the two lines, and directly on the length of parallelism and the value of the fault current. The voltage is also to some extent dependent upon the resistivity of the earth. External plant is designed so that under the most adverse fault conditions the maximum voltage induced in the telephone line shall not exceed 300 V. In spite of such design, however, the induced voltage in a telephone system may, under exceptional conditions, greatly exceed this figure.

Protection Requirements. The protective devices fitted in a telephone system must fulfil the following basic requirements:

(*a*) They must not operate with speech or signalling currents.

(*b*) They must not appreciably reduce the transmission or signalling efficiency of the telephone system.

(*c*) They must ensure that no voltage dangerous to life is allowed to persist on any part of the exchange equipment or subscribers' apparatus.

(*d*) They must prevent voltages being applied to the apparatus and wiring which would cause a breakdown of the insulation with the resultant risk of fire.

(*e*) They must limit any current passing through the wiring and equipment to a value which will not produce overheating to the extent of becoming a fire risk. In considering this risk it should be borne in mind that overheating may occur due to the passage of a heavy current for a short time or to the prolonged application of a much smaller current.

(*f*) They must prevent discharges through telephone apparatus which would injure the auditory system of any listening subscriber.

(*g*) They should, as far as possible, be self-restoring and should not materially increase the fault liability of the system.

(*h*) They must not be expensive owing to the large number required.

Protective Devices. Comprehensive protection against lightning and power lines is in practice

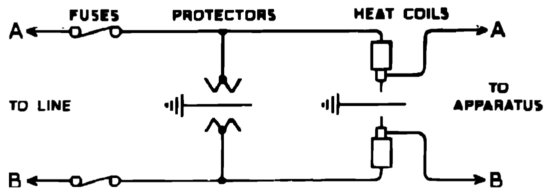


FIG. 406. SEQUENCE OF PROTECTIVE DEVICES

obtained by the employment of a combination of the following three devices:

(*a*) A spark gap (or gas discharge) protector which will earth the line when its potential above earth reaches a predetermined value.

(*b*) A fuse which will disconnect the line when the current reaches a dangerous level.

(*c*) A heat coil which will earth or disconnect the line after a suitable delay period if the current is such that prolonged application would cause damage to the equipment.

Fig. 406 indicates the normal method of interconnecting the fuses, protectors and heat coils at an exchange. If a current in excess of 1·5 A flows in the circuit the fuses will blow. Similarly if the line potential exceeds 500/750 V a discharge takes place across the protectors, and if the resultant current is of sufficient magnitude and duration the fuses will also blow. If the voltage is not excessive and if the current is between 0·3 and 1·5 A the heat coils will operate after a period of some 3 min. and will earth the lines. As before, the resulting current to earth may now blow the fuses.

The protective arrangements at a subscriber's premises are substantially the same as those at the main exchange with the exception that the heat coils are now omitted. Until recently, however, the subscriber's protector unit incorporated a type of heat coil which disconnected the circuit on operation instead of earthing the line.

Fuses. It is desirable that the design of a fuse should be such that it will blow quickly and quietly and without scattering molten metal whenever the current through it reaches a dangerous value. It should also be so designed that any arc which may

be set up when the fuse wire melts cannot be maintained. The line fuses used in the British Isles are invariably of the tubular pattern in which the fuse wire is enclosed in a porcelain, asbestos or ceramic tube with suitable metal end caps. In the Post Office, fuses are coded by two numbers

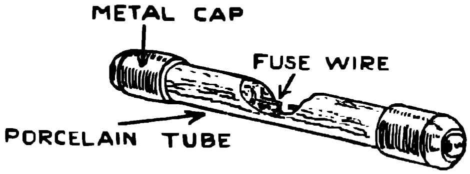


FIG. 407. FUSE No. 1/2

separated by an oblique stroke. The first number is the reference code of the fuse and the second number indicates the approximate rating current (to the nearest whole number). The rating current in each case is roughly half the fusing current.

Fig. 407 shows a common type of line fuse (Fuse No. 1/2) in which the phosphor-bronze fuse wire is inserted in a small bore porcelain tube with end caps without ventilation holes. It is rated at 1·5 A and "blows" at approximately 3 A. The tubular porcelain fuse is now rapidly being superseded by the fuse shown in Fig. 408 (Fuse No. 28/2). This fuse is enclosed in an asbestos tube held between two flat body pieces of pressboard. It is rated at 1·5 A and is specified to carry this current continuously without deterioration, whilst it must blow within 30 sec of the current reaching a value of 3 A. The acceptance specification also requires that, when connected in a circuit carrying 25 A at 500 V pressure, the fuse shall operate without fracturing or sparking. The fuse (No 37/3) adopted for the new type of subscribers' station protector

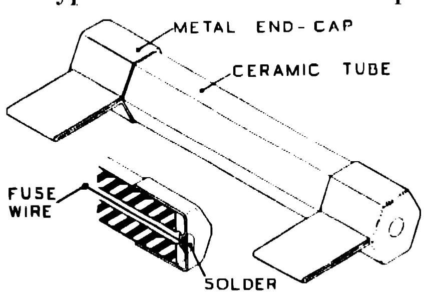


FIG. 409. FUSE No. 37/3

consists of a hexagonal ceramic tube with flat contact lugs (Fig. 409). The rating of the fuse is 2·5 A and it is designed to operate within 30 sec of the current reaching a value of 5 A. The flat spade contacts of fuses Nos. 28 and 37 are preferable to the cylindrical contact caps of the earlier fuses (e.g. No. 1). The cylindrical fuse suffers from the disability that a considerable flexing of the holding clips is necessary during the insertion or removal of the fuse, which often results in loose contact faults.

Protectors. The *protector* or protector element is that part of the safety devices which provides a direct path to earth for lightning or other high voltage discharges. The usual type of protector used on subscribers' lines and junction circuits consists of a small gap (in the order of 3 mils) between two conducting electrodes. The most common type (Protector No. 14) consists of two moulded carbon blocks (Fig. 410) held together by the mounting springs. The inner surface of each block is flat with bevelled edges. The discharge surface and the surrounding bevels are coated firstly with a thin film of red anti-dust varnish and secondly with a film of insulating varnish with

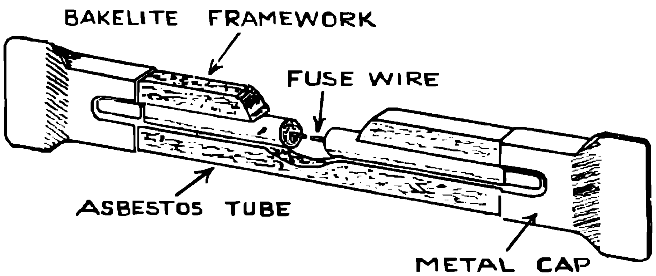


FIG. 408. FUSE No. 28/2

a clear cellulose acetate base and approximately 1·5 mil thick. The protector has a specified discharge voltage of from 500 to 750 V.

The earlier types of carbon block protector had a thin perforated mica separator instead of the varnish film. A fusible plug was also fitted to one block of the pair with the intention that a persistent discharge would melt the plug and permanently earth the line. It was found, however, that in practice a discharge sufficiently heavy to melt the plug also blew the line fuses. In addition, the mica separator was very liable to introduce low insulation faults due to the accumulation of dust between the electrodes.

The carbon block type of protector is now being replaced by a new one-piece moulded type (Fig. 411). The new protector (Protector Electrode 1A) consists of two channel-section brass electrodes separated by a perforated insulating film, the whole (apart from the contact surfaces of the electrode) being enclosed in a translucent moulding of high insulation resistance. The electrode is interchangeable with a pair of carbon protectors, whilst

the complete sealing of the air gap together with the one-piece construction minimizes low insulation troubles and ensures a more consistent breakdown voltage (750 $\pm$ 150 V).

Gas Discharge Protectors. The normal design of lightning protector is such that it is difficult to obtain the very high degree of accuracy necessary to ensure consistent breakdown voltage. Hence protectors of normal design cannot be relied upon to discharge both lines of a circuit to earth simultaneously, and there is some risk of acoustic shock. Moreover, whilst the carbon block or brass electrode protector will cater for most lightning discharges, they are not very satisfactory for dealing with very heavy lightning discharges or conditions resulting from contacts with high-pressure power lines. The current resulting from a heavy lightning discharge or from a contact with a high-voltage power line would in most cases be sufficient to destroy or seriously damage the protector unit.

It is probable that increasing use will be made in the future of the gas discharge principle for the protection of telephone plant against high voltages. The gas discharge protector consists essentially of two or more electrodes sealed in an envelope containing some form of inert gas. If the p.d. across the electrodes rises to a certain critical value (the *striking voltage*), the gas is ionized and becomes conducting. The resultant arc continues until the p.d. across the electrodes falls below a further

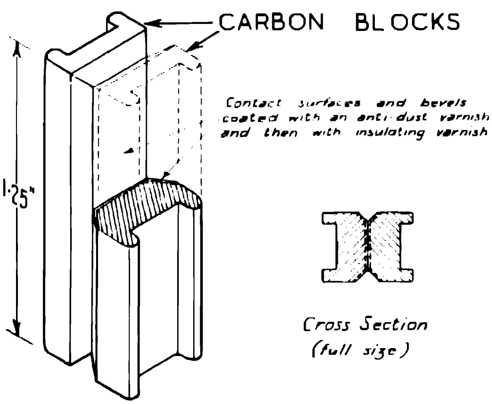


FIG. 410. CARBON BLOCK PROTECTOR
(Protector No. 14)

critical value (the *extinction voltage*) which is somewhat less than the striking voltage. By connecting one electrode to line and the second electrode to earth, the protector provides a low impedance path to earth when the line voltage exceeds a predetermined value. For normal voltages, however, the gas discharge protector has an extremely high impedance and the transmission loss is negligible. The advantage of the gas discharge protector is that it can be designed to carry heavy currents, and the wider spacing of the electrodes permits of a more consistent striking voltage. On the other hand the gas discharge protector is more bulky and costly than the simple air-gap type of

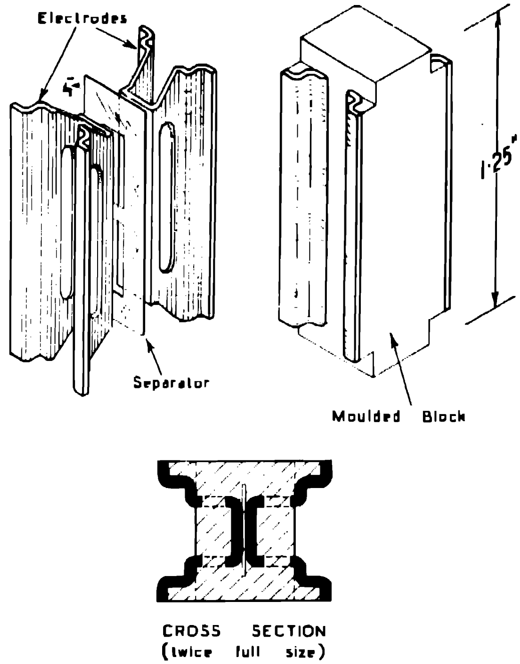


FIG. 411. ONE-PIECE MOULDED PROTECTOR
(Protector Electrode No. 1A)

protector. It has therefore, up to the present time, been mainly used to protect lines where there is a special danger from high pressure power lines.

Fig. 412 shows a portion of a panel of gas discharge protectors designed to safeguard telephone lines from high voltage surges. The protector illustrated is manufactured by Edison Swan Cables, Ltd., and consists of three tungsten electrodes in a mixture of inert gases (mainly neon) enclosed in an envelope of special glass. Two of the electrodes are for connexion to the lines and are terminated on a standard E.S. lamp cap. The third or earth electrode is led out at the opposite end of the glass envelope and is terminated on a simple screwed stem with terminal nut. There are two sizes of protector. The larger and more common type is rated to carry 10 A per line (total 20 A) without deterioration, whilst the small type is rated at 1 A per line. The 10 A type is recommended for overhead lines, and the 1 A type is intended for underground cables. The striking voltage of the

tubes is 150 to 250 V with an extinction potential of about 100 to 150 V. It is important that, during manufacture, all foreign matter should be eliminated from the glass, electrodes and gas to ensure consistent characteristics of the tube in service. Accurate spacing of the electrodes is also important in order to ensure that both lines discharge to earth simultaneously.

Heat Coils. The standard exchange type of heat coil (Type BB) consists of a coil of double silk-covered nickel wire wound on a small copper tube. The resistance of the winding is approximately 3·5 to 4·1 Ω. The copper tube (Fig. 413) is fixed to the central pin of the heat coil by a special solder (lead 28%, cadmium 34%, bismuth 28%, tin 10%) of low melting point and is protected by a black fibre sleeve open at one end. One connexion of the resistance coil is soldered to the copper tube, whilst the other end of the coil is fixed to the brass end cap. The heat coil is mounted between spring clips which tend to force the copper tube into the protective cover. The coil is designed to carry a current of up to 350 mA for 3 h without operating, but if the current exceeds this value the cumulative heating effect melts the solder and allows the spring pressure to force the tube into the fibre sleeve. The consequent movement of the mounting spring is arranged to earth the line. The heat coil is specified to operate within 210 sec if the current through it is 500 mA.

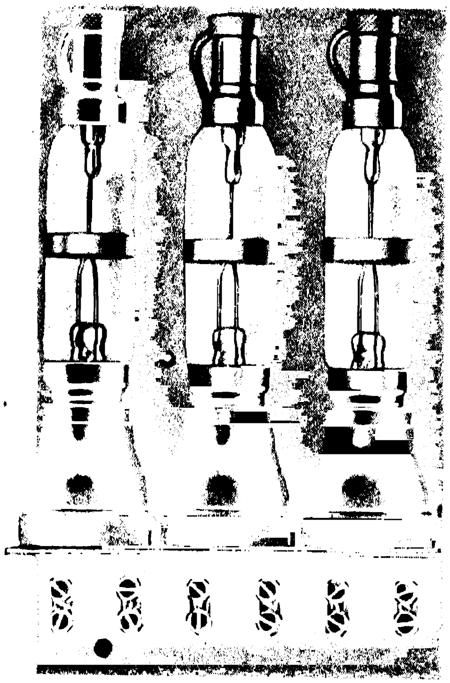


Fig. 412. Gas Discharge Protectors

Fig. 414 shows another type of heat coil (Type A) which has been used extensively in the past at subscribers' premises. The principle of operation is the same, but the melting of the solder in this case releases a pin (under spring tension) and so disconnects the line. The Type A heat coil is of somewhat higher resistance (4·5 to 5·5 Ω) and is specified to operate with 500 mA within 60 sec.

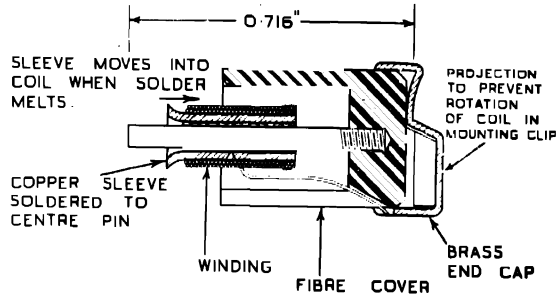


Fig. 413. Earthing Type Heat Coil
(Heat Coil BB)

Heat coils of the present design are somewhat erratic in their operation. In recent years several forms of delayed action fuses have been tried with a view to obtaining a more reliable component. In principle these delayed action fuses consist of a helix of thin tinfoil wrapped round an insulating rod of high specific heat and good thermal conductivity. The insulating body acts as a heat reservoir and so delays the action of the fuse when large currents are passed for a short time. Various materials have been tried for the heat-absorbing base of the fuse, but ordinary soda glass was found to be the most satisfactory. The electrical characteristics of the experimental delayed action fuses are substantially the same as those of the type BB heat coil.

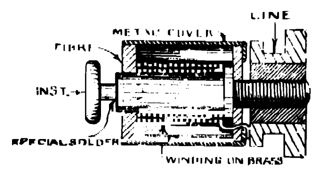


Fig. 414. Disconnexion Type Heat Coil
(Heat Coil A)

Subscribers' Protectors. Fig. 415 shows a common type of protector unit fitted at subscribers' premises. The base of the protector is of porcelain and accommodates two cylindrical line fuses, a pair of carbon block protectors and two heat coils of the disconnexion type. The whole unit is fitted with a cover with a single hole fixing screw. The latest and current standard protector (Fig. 416) is

appreciably smaller and omits the heat coils. The incoming lines are terminated on the lower terminals and the circuit is passed through a pair of fuses of 2·5 A rating. The wiring from the instrument is terminated on the upper terminals, and spark-gap protectors of the new moulded type are connected between the instrument terminals and the earth terminal. The new protector is some 4 in. × 1½ in. and is normally fitted with a black plastic cover to exclude dust. The same protector can, however, be mounted along with others under a common cover to form a larger unit for use at private branch exchanges and in similar circumstances where a number of lines are led in at the same point.

system of wiring but also facilitates maintenance and reduces the strain on the connexion tags.

Some difficulties have been experienced in maintaining a high standard of insulation resistance with fuse mountings of the 4001 type. Moreover, this mounting is somewhat liable to high resistance contact faults due to loose fuses and to fuses being

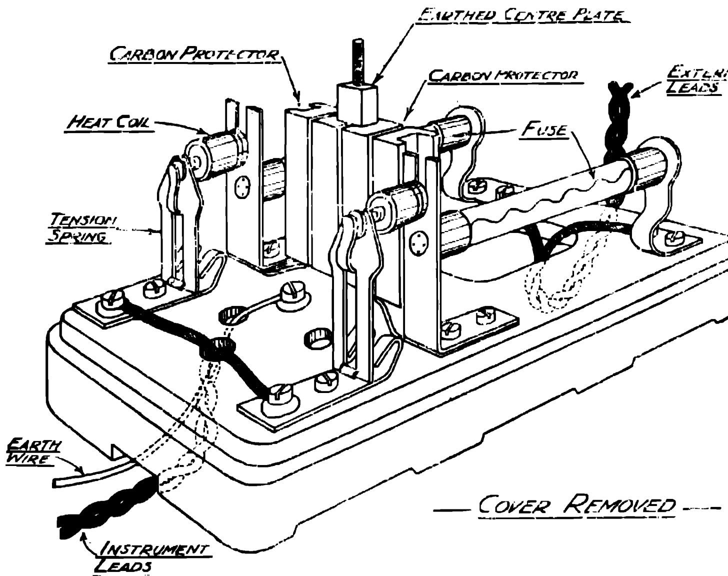


FIG. 415. FUSE, HEAT-COIL, AND PROTECTOR UNIT FOR USE AT SUBSCRIBERS' PREMISES
(Cover not shown)

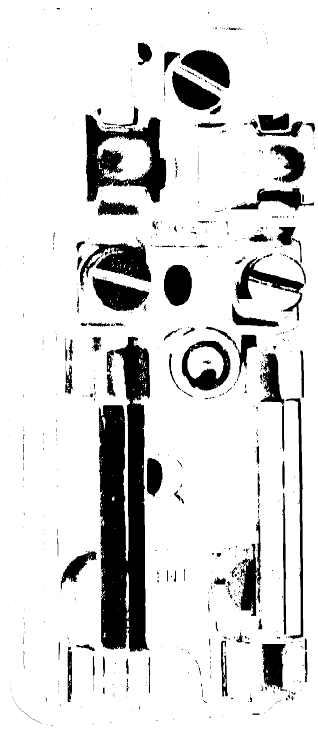


FIG. 416. NEW TYPE OF SUBSCRIBERS' PROTECTOR
(Protector and Fuse 1⅔)

Fuse, Heat Coil, and Protector Mountings. It is the normal practice in telephone exchanges to mount the heat coils and lightning protectors as one combined unit and the fuses as a separate unit. Fig. 417 shows a very common type of fuse mounting (No. 4001) for twenty circuits, i.e. forty fuses. The fuses are of the cylindrical type (No. 1/2) and are held in position by spring clips. The pair of fuses serving one line are on opposite sides of the mounting and the connexion tags are arranged so that the permanent wiring to the external cables is on the left side, whilst the internal wiring is taken from the right hand side of the mounting. The fuse mounting is provided with a hard wood *fanning strip* which not only ensures a neat and orderly

rotated in their clips so that an oxidized or dirty portion of the fuse is in contact with the clip. The fuse mounting (No. 4028) illustrated in Fig. 418 was designed originally for use on trunk and junction circuits, but will in future supersede the No. 4001 mounting for all purposes. The 4028 type mounting is of the skeleton type made up of ebonite strips to reduce surface leakage. There is capacity for forty fuses of the flat type (No. 28/2). The wiring tags of the fuse mounting are on the inside and access for wiring and maintenance is obtained by hinging each half of the unit. A cover is provided which completely encloses the fuses and so minimizes low insulation faults due to dust.

The most common type of heat coil and protector

mounting (Protector H.C. & T. 40B) is illustrated in Fig. 419, whilst Fig. 420 shows the arrangement of the contact springs in somewhat more detail. The two lightning protectors of each circuit are held between the external line springs and the centre plate of the mounting which is earthed. Similarly, the heat coils are held between the internal and external line springs in such a way that when the heat coil operates a small contact spring attached to the external line spring is pressed against a projection of the earth connected centre plate. In addition to providing accommodation for the heat coils and protectors, this mounting is designed to allow of the insertion of a special U-shaped test clip which, by separating the outer springs, breaks both wires of the circuit and enables tests to be made of the circuit inside and outside the exchange.

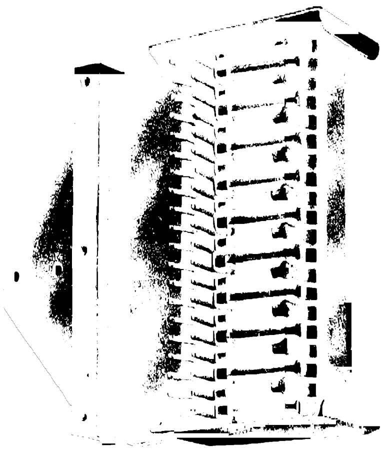


FIG. 417. FUSE MOUNTING (No. 4001)

Main Distribution Frame. The subscribers' lines enter an exchange in a number of large capacity underground cables, each of which serves a different part of the exchange area. The numbers allocated to subscribers' lines do not of course bear any relationship to the geographical location of the subscribers, and hence the exchange numbers included in any one cable are entirely haphazard. Moreover, as subscribers cease to have the telephone and new subscribers are connected, the exchange numbering of the external cable pairs is constantly changing. On the other hand, all lines within the exchange are in strict numerical order and it is apparent that some means must be provided for temporarily connecting, as desired, any underground cable pair with any number of the exchange numbering scheme. This conversion from the geographical order of the external pairs to the numerical order within the exchange is carried out on a *Main Distribution Frame* (M.D.F.). In addition to its major function, the Main Distribution Frame also provides:

(*a*) A suitable location for the mounting of the fuses, heat coils, and protectors.

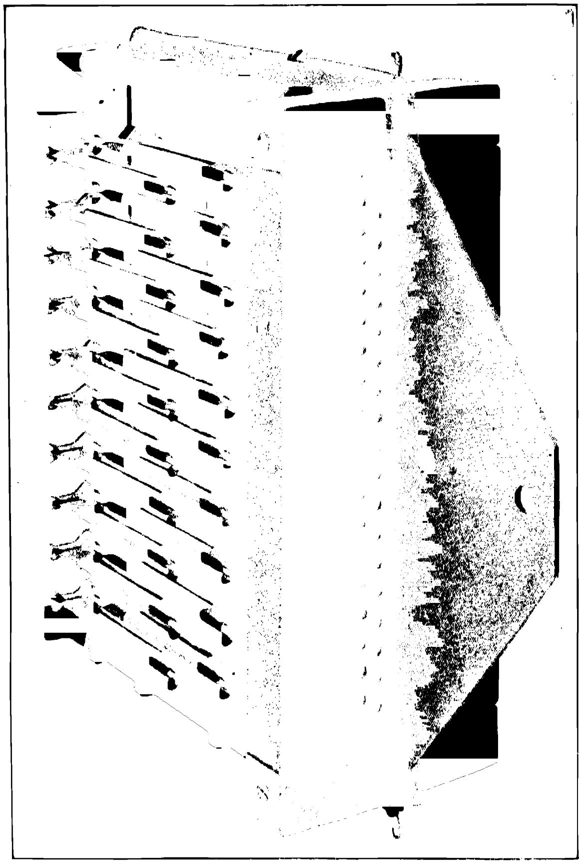


FIG. 418. HIGH INSULATION FUSE MOUNTING (No. 4028)

(*b*) A point for the termination of the external and the internal cables.

(*c*) A convenient place to break into any circuit to test the conditions both inside and outside the exchange.

The M.D.F. (Fig. 421) is built up of the required number of vertical sections (or *verticals*) each constructed of angle and flat steel bars. The verticals are tied together by longitudinal members and the rigidity of the frame is still further increased by sinking the foot in cement. The terminating cables

of the underground circuits are led up and tied to the centre angle iron, twenty pairs being laced out at each horizontal arm for termination on the tags of each fuse mounting.

The internal switchboard cables are fed down the centre upright of each vertical from an overhead cable runway and then horizontally to the protector strip. Cross-connexions between the two sides of the frame are carried out by means of *jumper wire* which is soldered to the appropriate tags of the fuse and protector mountings. In order to provide for a systematic arrangement of jumpers, it is arranged that all jumpers run horizontally on the line side of the main uprights and vertically on the exchange side of these uprights. Ebonite-coated iron rings (*jumper rings*) are fixed on each horizontal member near the fuse mounting.

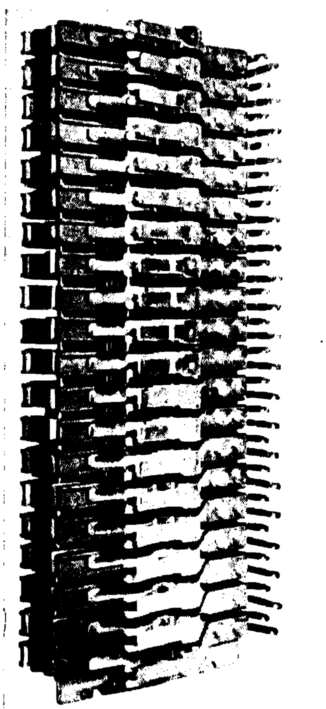


FIG. 419. PROTECTOR AND HEAT COIL MOUNTING (Protector H.C. and T. 40B)

Similar but somewhat larger rings are fixed to the longitudinal members near each upright. If, for example, it is desired to jumper from the bottom fuse mounting on vertical No. 10 to the top protector mounting on vertical No. 25, the jumper wire is led through the fanning strip behind the fuse mounting, through the jumper ring on the same horizontal arm and then horizontally along the frame to the jumper ring near the centre upright of vertical No. 25. After passing through this ring the jumper is led vertically upwards to enter the appropriate hole in the fanning strip of the top protector mounting. It is interesting to note that on the M.D.F., as on all other similar frames, the permanent cabling is terminated on the left-hand side (when viewed from the front) of the fuse

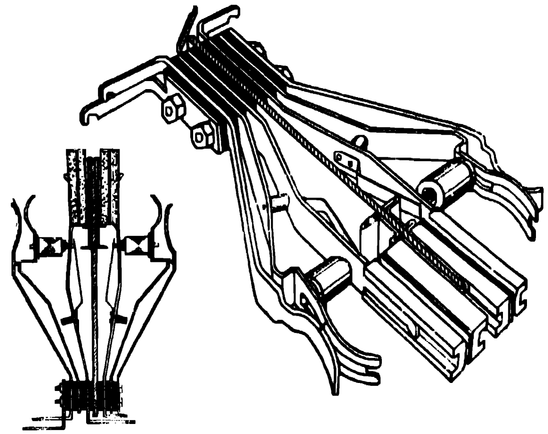


FIG. 420. ARRANGEMENT OF CONTACT SPRINGS ON PROTECTOR UNIT

and protector mountings, so as to leave the more convenient right-hand side for jumpering.

The height of the M.D.F. in large exchanges is dependent upon the clear height of the room, but in general, with rooms of 12 ft clear height, each vertical has capacity for 200 circuits (ten protector mountings) on the exchange side and 220 circuits (eleven fuse mountings) on the line side. The greater capacity on the line side is necessary since there must always be a greater number of external pairs than exchange numbers to cater for the limited availability of the cable pairs to any one subscriber.

Travelling ladders are usually provided on Main Distribution Frames up to average size, but in very large exchanges the volume of work to be carried out on the M.D.F. justifies the provision of a mezzanine platform. (See Fig. 421.)

Leading-in of External Cables. The architectural design of a telephone exchange building is dependent on the size and shape of the available site; whilst the direction in which the underground cables enter the building is dependent upon the lay-out of the external plant. The ideal condition is attained when the cables enter at one end of the building basement and are run directly beneath the M.D.F. and near to the outside wall so that the cables may be carried on bearers and through

short lengths of iron pipe passing through the basement ceiling to the foot of each M.D.F. vertical (Figs. 422 and 423). The pipes project 2 in. or 3 in. above the apparatus room floor level to prevent risk of damage to the cables during floor-cleaning operations. The paper-core underground cables are jointed to enamelled silk- and wool-covered cables which are laced out on the frame and terminated on the fuse mountings. The paper core cable is, for reasons of insulation and economy, carried as close as possible to the terminating point in order that the length of silk and wool cable may be reduced to a minimum.

In exchanges where one or more floors intervene between the cable chamber and the room in which the M.D.F. is located, ducts are built either into the wall of the building or are supported on the surface of the wall. These ducts terminate in a cable chase between the wall of the building and the M.D.F. which is covered by removable teak covers. The cables are led up to the M.D.F. through the ducts and the joint is made in the cable chase

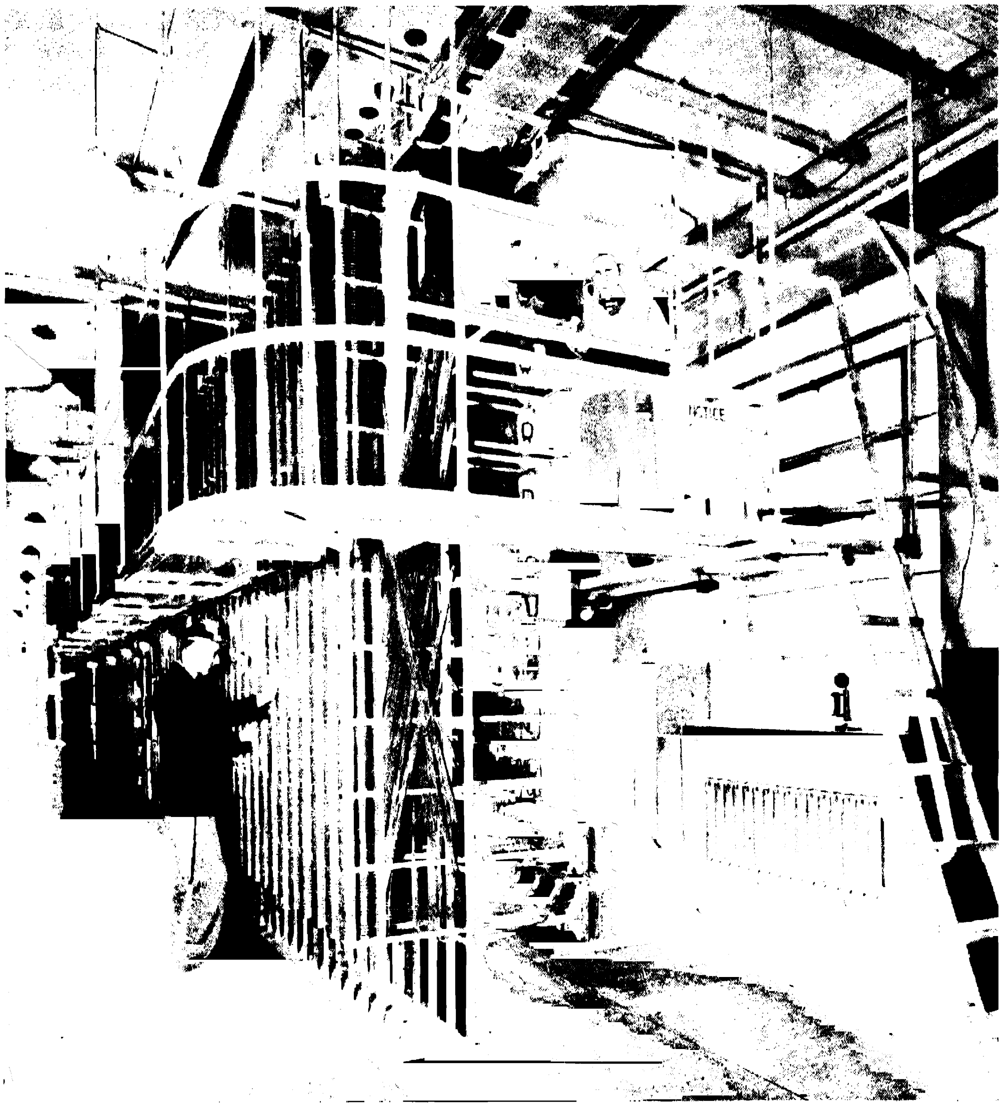


FIG. 421. MAIN DISTRIBUTION FRAME WITH MEZZANINE PLATFORM

with the tails passing to each vertical through slots in the teak covers.

In long vertical runs between the cable chamber and the M.D.F. the cables require supporting at intervals. A very neat arrangement may be made by sweating lead strips, known as *plumber's tacks*, to the cable sheath and fixing these to wall brackets, the whole being enclosed in a wooden casing. In small exchanges where there is no cable chamber below the M.D.F., the cables pass direct from the manhole into a raised floor alongside the M.D.F. (Fig. 424) and are there connected to the enamelled silk and wool terminating cables.

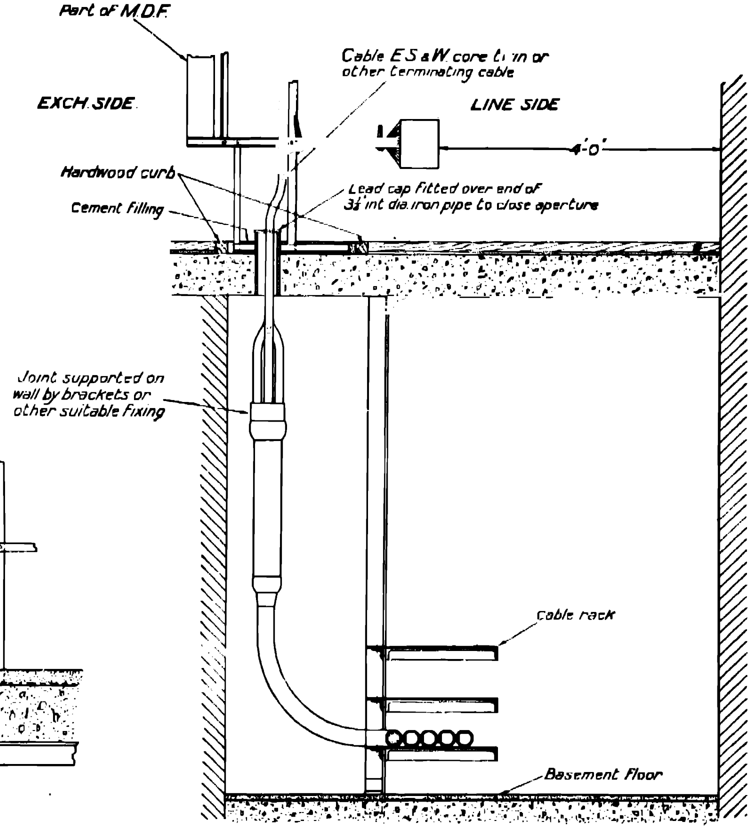


FIG. 422. LEADING IN STREET CABLES FROM CABLE CHAMBER TO M.D.F.

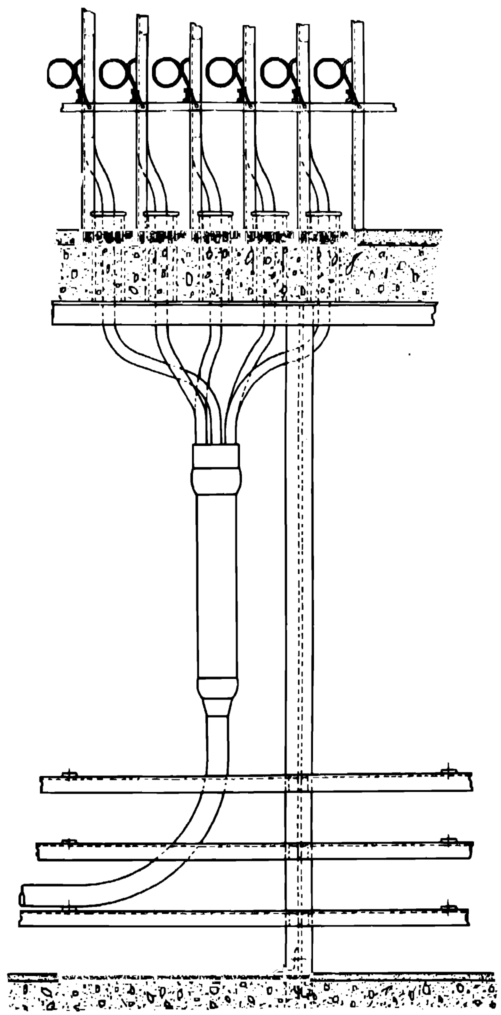


FIG. 423. SECTIONAL ELEVATION OF FIG. 422

Earthing Systems. An earth connexion is necessary at a telephone exchange for the following purposes:

(*a*) To reduce the risk of crosstalk due to the lines and equipment assuming an indefinite voltage with respect to earth.

(*b*) To complete a circuit for signalling currents and for P.B.X. power leads.

(*c*) To avoid the risk of shock should apparatus racks, etc., come in contact with high voltage power lines.

(*d*) To provide a direct connexion with earth for lightning protection.

(*e*) To enable single-pole switching to be used on the exchange power plant.

(*f*) To provide a means of earthing electrostatic screens on apparatus, etc.

It has been found from experience that the resistance of an earth system under the most adverse conditions (i.e. after a prolonged dry

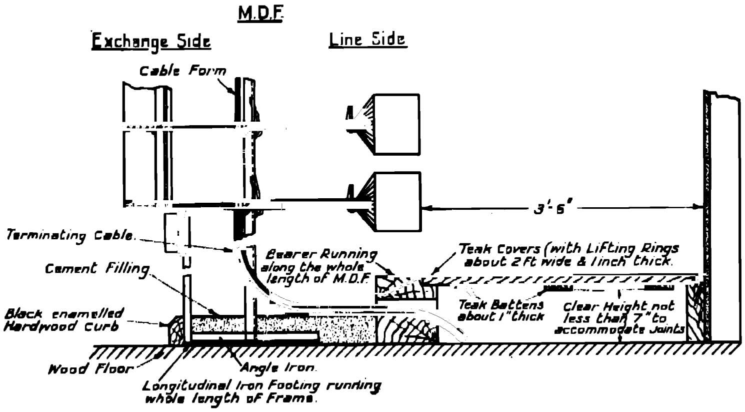


FIG. 424. RAISED FLOOR FOR LEADING IN STREET CABLES

spell) should not exceed 8 Ω. Most exchange earths are very much less than this figure.

The normal exchange earth system consists of a number of 6 ft long 1 in. diameter galvanized steel

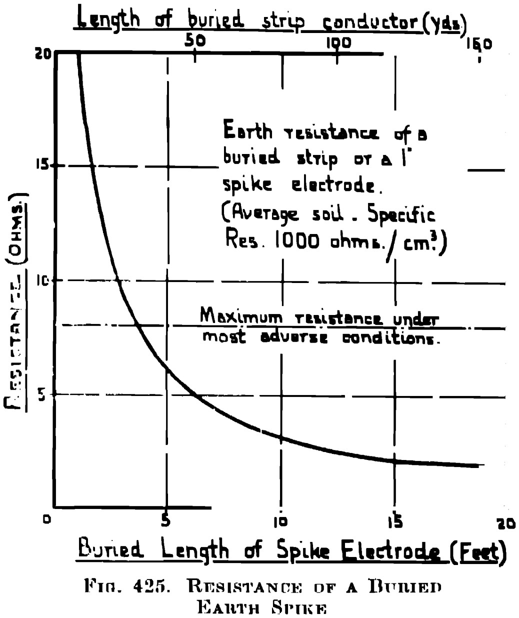


FIG. 425. RESISTANCE OF A BURIED EARTH SPIKE

pipes driven vertically in the ground to their full length. The spikes are connected together by means of a 19/16 stranded copper cable which is led into the exchange via the cable chamber and is terminated on the M.D.F. The feeder cable is enclosed in a lead pipe of suitable size to prevent corrosion. It is important that the spikes should be driven in to their full length to ensure a low earth resistance. Fig. 425 shows how the earth resistance of a spike varies with the depth to which it is driven. The resistance decreases rapidly as the depth is increased to about 6 ft, but beyond that depth the decrease does not warrant the additional cost. If space is available, the number of spikes of an exchange earth system should not be less than twenty to provide the necessary safety margin. Fig. 426 shows how the combined resistance of two spikes decreases as the separation between them is increased. It is apparent that to obtain the maximum benefit the separation between adjacent spikes must be a minimum of 8 ft but there is little to be gained by increasing the separation to much more than this figure. It is preferable that the electrodes and feeder cable be doubled back upon themselves to minimize the high-frequency impedance of the system. Fig. 427 shows a typical lay-out for an earth electrode system at an exchange. As a rough approximation it can be assumed that the effective resistance of an electrode system of this type is $1 \cdot 5/N$ of the resistance of a single spike, where N is the number of spikes.

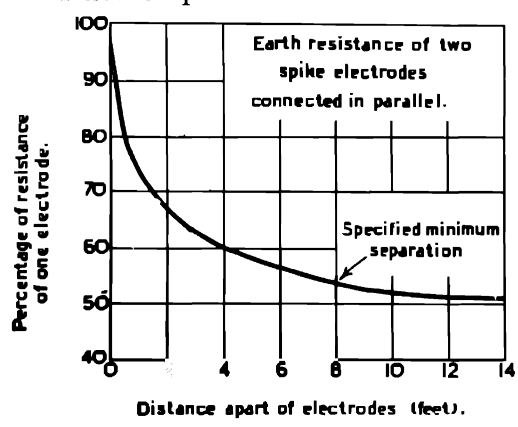


FIG. 426. JOINT RESISTANCE OF TWO EARTH ELECTRODES IN PARALLEL

When rock is encountered at a shallow depth an alternative form of earth system may be made up from a continuous lead strip (2 in. wide) buried at a depth of from 2 to 3 ft. A minimum of 80 ft of

strip is normally required, and it should be laid in accordance with the principles laid down for spike electrodes, i.e. if the strip is in the form of a loop there should be a minimum separation of 8 ft between the sides of the loop. Fig. 425 shows the earth resistance to be expected from different lengths of strip. Occasionally, where space on the exchange site is limited, the lead strip is laid under a new cable duct route leading to the exchange.

As an alternative to earth spikes or lead strip, large galvanized iron earth plates may be sunk when the site space is very limited. The plates should be buried to a depth where the surrounding soil will remain wet at all seasons of the year, and the excavation must be large enough to give a separation between plates of at least 3 ft, and where economically practicable this spacing should be increased up to 8 ft.

For the earth connexion at subscribers' premises use is often made of a main water supply pipe (Fig. 428). If this is not available, a single earth spike or a small earth plate will usually suffice. The earth lead in these circumstances is usually of 3/20 stranded copper.

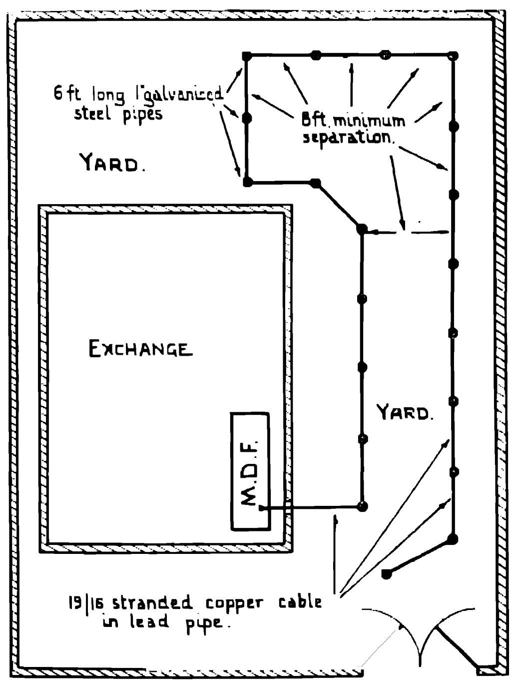


FIG. 427. TYPICAL EARTH SYSTEM OF AN EXCHANGE

Intermediate Distribution Frame. The traffic originated by different subscribers in the same exchange varies considerably. Subscriber No. 1234 may, for example, be an active business subscriber who originates as many as twelve calls in the busy hour of the day. Subscriber No. 1235 may, on the other hand, be a residential subscriber who originates say only one call in the busy hour once every four or five days. It would therefore be impracticable to allocate subscribers to each operator on a strict numerical basis. One method of providing a uniform load to all operators is the provision of multiple answering equipment, i.e. the repetition of each subscriber's calling equipment along the switchboard, so that any free operator can answer any call. This scheme has been used by certain administrations abroad for small and medium size exchanges, but has not been adopted in this country for subscribers' lines owing to the limitations imposed on the capacity of the switchboard due to the space required by the additional calling equipment.

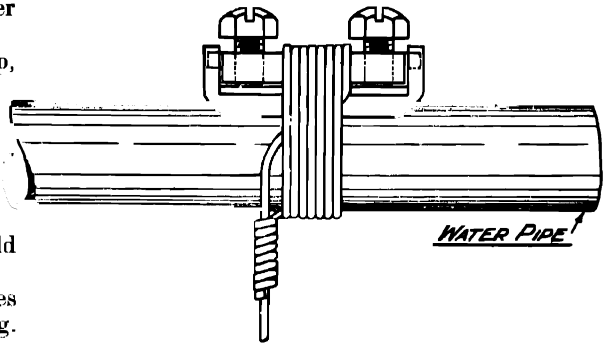


FIG. 428. METHOD OF CONNECTING EARTH LEAD TO WATER MAIN
(Earth Clip No. 3)

Without multiple answering facilities it becomes necessary to provide a means of distributing the subscribers' lines over the operator's positions in such a manner that the total traffic offered to each operator is roughly the same. To effect this distribution, the answering equipments on each position are cabled to an *Intermediate Distribution Frame* (I.D.F.), which is so arranged that any subscriber's number can be temporarily connected by means of a jumper wire to a calling equipment on any desired position.

The function of the I.D.F. is illustrated in Fig. 429, where the figures in parenthesis indicate the number of calls originated by each subscriber in the busy hour. The same figure also shows the function of the M.D.F. in changing from the geographical order of the external cables to the numerical order within the exchange. It will be noted that the two sides of the I.D.F. are designated *Local* and *Multiple*. The circuits on the multiple side are

arranged in strict numerical order, whereas the connexions to the local side are in switchboard panel order.

The I.D.F. also provides a convenient point for the termination of the cables from the switchboard on the switchboard and for introducing into the circuit the required signalling equipment.

Junctions, like subscribers' lines, are terminated on the line side of the M.D.F. and are jumpered to protectors or connexion strips on the exchange

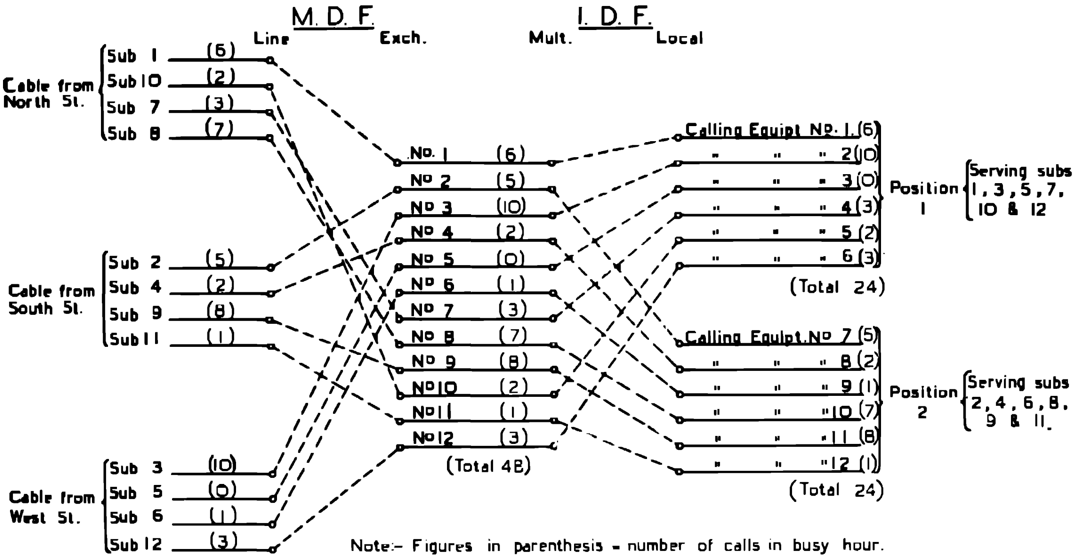


Fig. 429. Illustrating the Purpose of Main and Intermediate Distribution Frames

multiple jacks, and the usual cabling arrangements of a subscriber's line are as illustrated in Fig. 430. If, as in a large exchange, there are two suites of switchboards, the multiple cables are often brought down separately to the I.D.F. and commoned together there on the same tags.

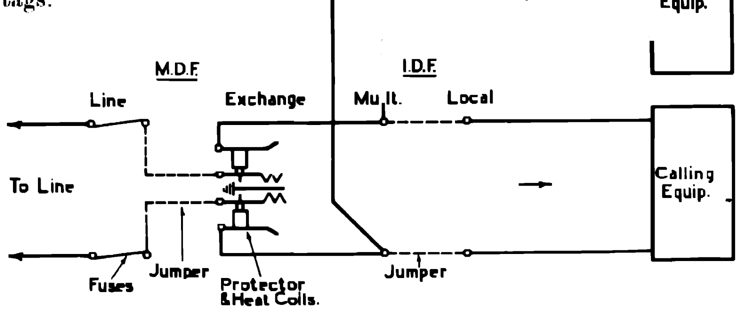


Fig. 430. General Cabling Arrangements for Subscribers' Lines

Although the I.D.F. was originally introduced for the purpose of cross-connecting the calling equipments and the subscribers' multiple numbers, it is nowadays (especially in automatic and auto-manual exchanges) extensively used for connecting junction lines with any incoming or outgoing jack side. A bank of tie cables extends the circuits to the multiple side of the I.D.F. Here a relay group giving the required signalling facilities is jumpered in (Fig. 431) and a second I.D.F. jumper connects the switchboard side of the relay group to the outgoing junction multiple or answering jack via the I.D.F. local. It will be noted that the junction answering jacks and the outgoing junction multiple are both cabled to the local side of the I.D.F., whereas the subscriber's outgoing multiple (being in unalterable numerical order) is cabled to the multiple side of the I.D.F.

The construction of the I.D.F. (Fig. 432) is somewhat similar to that of the M.D.F. and is designed so that all jumpers shall run horizontally on the local side of the frame and vertically on the multiple side of the frame. Jumper rings are provided as on the M.D.F. and a guard rail prevents damage to the connexion strips due to accidental impact by ladders, etc.

In most manual exchanges and in the earlier automatic exchanges, the connexion strips on the

local side of the I.D.F. were arranged horizontally, thereby giving the maximum space between adjacent rows of strips to facilitate jumpering. It has been found, however, that the horizontal connexion strips are liable to collect dust and stray solder from the jumpering operations, and in modern practice it is usual to arrange the connexion strips vertically on both the multiple and local sides of the frame. $6\frac{1}{2}$ in. connexion strips are employed on the local side, and 8 in. strips on the multiple side of the frame, the former giving a

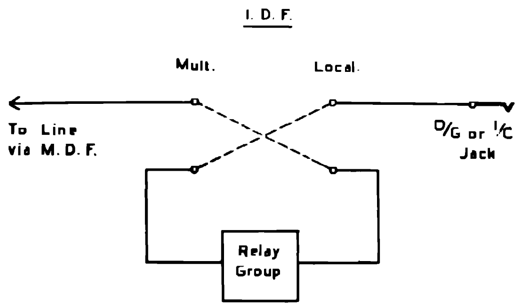


FIG. 431. CABLING OF JUNCTIONS

space between adjacent strips on the same vertical of some $1\frac{1}{2}$ in. to allow the jumpers to be run horizontally along the frame.

It is usual to install an I.D.F. with the same number of circuits per vertical as the number on the exchange side of the M.D.F. This, together with the same spacing ($6\frac{3}{4}$ in.) between verticals on each frame, allows of a comparatively straightforward cabling scheme between the two frames.

Combined Distribution Frame. At exchanges of less than about 2000 lines ultimate capacity, the provision of separate frames for main and intermediate distribution is not warranted, and a combined main and intermediate distribution frame is provided. The *Combined Distribution Frame* is of similar construction to the separate frames, the lower portion being equipped with fuse and protector mountings, whilst the I.D.F. connexion strips are mounted above. Apart from economies in the cost of the frame structure, the adoption of a combined frame also effects considerable savings in the cable costs between the protectors and the multiple side of the I.D.F.

In very small manual exchanges the I.D.F. is sometimes mounted in a special section which is installed alongside the switchboard positions.

Terminal or Connexion Strips. It is not always practicable or desirable to terminate cables direct on to the apparatus tags. In these circumstances a *connexion strip* is employed and the conductors of the various cables and wiring are soldered as required to the tags of the strip.

There are numerous forms of connexion strips

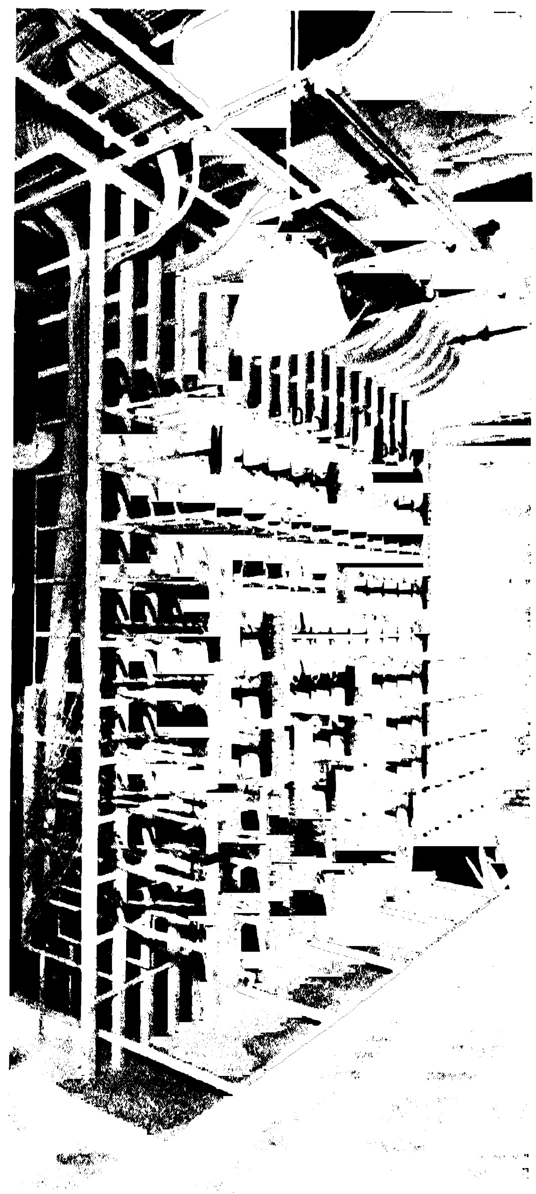


FIG. 432. INTERMEDIATE DISTRIBUTION FRAME

designed for use in special circumstances but, apart from these, the standard strip used throughout telephone exchanges of all types is of the form illustrated in Fig. 433. To line up with the size

of switchboard cables, jack strips, etc., the majority of connexion strips have twenty rows, each row consisting of from 2–8 tags, (i.e. two-way, eight-way, etc., connexion strips). There are two standard lengths of 6½ in. and 8 in. overall. The tinned copper tags have notches to hold the conductors, and are built up into an ebonite block in such a manner that the tags do not loosen with the heat of soldering. A hard wood "fanning strip" with holes ensures that the wiring is led neatly to the

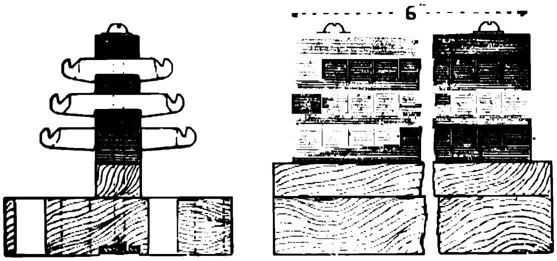


FIG. 433. TYPICAL CONNEXION STRIP (3 × 20)

tags. The front edge of the strip is usually utilized for the signwriting which indicates the designation of the circuits appearing on the connexion strip.

Wiring and Cabling Arrangements. The wiring arrangements of the subscribers' lines and switching equipment in a telephone exchange are governed largely by cost considerations, the necessity for reliability, ease of wiring and maintenance, and of course, freedom from interference between circuits. The gauge of the individual conductors is generally small owing to the very small currents involved, and is largely governed by the requirements for mechanical strength rather than by electrical limitations. Nevertheless the large number of wires required necessitates careful design to avoid excessive bulk. Moreover the large number of circuits entails the adoption of a somewhat elaborate system of colour coding in order that the wires of various circuits may be distinguished. Enamelled conductors are not favoured for general use owing to the difficulty of baring the conductor for termination. Enamelled wire is however invariably used for tropical conditions, and occasionally in this country where high relative humidities are encountered, e.g. in unheated buildings. Otherwise tinned copper conductors insulated with cotton and silk lappings are usual, and the very high degree of insulation required is maintained by impregnating all exposed wiring with beeswax. In order to minimize interference and out-of-balance conditions on the speaking conductors, it is the universal rule in all exchange wiring that the conversational conductors shall always be wired as a twisted pair. In recent years metallically screened conductors have been introduced for leads which might possibly cause interference with adjacent speech circuits.

Apart from the distribution of power, the majority of the wiring of a telephone exchange is carried out with the following types of wiring:

Switchboard Cable. When there are large groups of similar circuits to be wired between two points, it is usual to employ multi-wire cables which, besides being compact, provide full mechanical and electrical protection to the enclosed wires. *Switchboard cable* is made in a variety of sizes with oval, round, or flat cross-section. Although switchboard cable, as its name implies, was originally intended for the wiring of switchboard jacks, it is now used extensively for all types of cabling. Switchboard jacks are invariably in strips of ten or twenty circuits and hence the majority of the standard switchboard cables are made up in units of twenty circuits. This unit has also been adhered to wherever possible in the design of such items as connexion strips, fuse and protector mountings, subscribers meters, relays, etc. In the past it was usual to include in each cable a spare circuit for use in the event of a fault developing on one of the twenty working circuits, but this practice has now been largely discontinued.

The general make-up of a switchboard cable is shown in Fig. 434. The conductors themselves are of annealed copper evenly coated with tin to facilitate soldering. The conductors are tightly covered with one lapping of undyed silk and then with a lapping of wool coloured as required for identification purposes. The two coverings are laid on in alternate directions. The insulated conductors are made up either in twisted pairs or as triples, and each unit is whipped with an open spiral of wool thread. The twins, triples, etc., are laid up to form the core of the cable. Usually round cable is employed for automatic exchange construction, but the cables used for the wiring of switchboard jacks are of the oval or flat type in order to keep the height of the cabling equal to that of the jack field. In flat cables the wires are arranged round a presspahn strip which forms the core of the cable.

The conductors are now lapped successively with cotton, paper tape, leadfoil tape, oiled paper tape and cotton and finally the whole is evenly and tightly braided with corded grey cotton which is impregnated with grey flame-proof paint. In damp situations similar cables but with the addition of a lead sheath are often employed.

A standard colour code is adopted for the

identification of individual conductors in a switchboard cable. The colour code consists of various combinations of eight basic colours, viz. blue, orange, green, brown, slate, white, red, and black, as shown in Table V.

The more common types of switchboard cable are shown in Table VI which gives the external diameter, general make-up, and colour code employed for each type. The 60-wire cable is possibly the most common size since it provides for twenty circuits each of three wires (two speaking wires and a third control wire). This cable is made up in the form of twenty groups of three wires. One of the three wires in each group is white, the second wire is a single or double colour combination of the blue, orange, green, brown, slate series, whilst the third wire has the same colours as the second conductor, but with the addition of red.

Cable Waxing. The exposed ends of switchboard cable are invariably waxed to prevent moisture penetrating and impairing the insulation, and also to avoid the unravelling of the silk and wool coverings of the individual conductors. Good quality beeswax is always employed. The cable ends to be waxed are immersed in molten wax at a temperature between 300° F and 350° F. The conductors should remain in the wax until air bubbles cease to rise in order to ensure that the

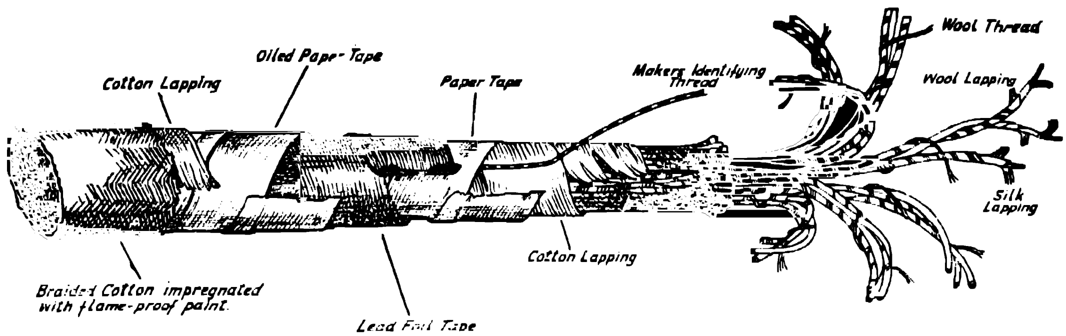


Fig. 434. Make-up of a Typical Switchboard Cable

TABLE V

Colour Scheme of Switchboard Cables

Conductor No.	Colour	Conductor No.	Colour	Conductor No.	Colour	Conductor No.	Colour
1	Blue	31	Red, blue	61	Black, blue	91	Red, black, blue
2	Orange	32	Red, orange	62	Black, orange	92	Red, black, orange
3	Green	33	Red, green	63	Black, green	93	Red, black, green
4	Brown	34	Red, brown	64	Black, brown	94	Red, black, brown
5	Slate	35	Red, slate	65	Black, slate	95	Red, black, slate
6	Blue, white	36	Red, blue, white	66	Black, blue, white	96	Red, black, blue, white
7	Blue, orange	37	Red, blue, orange	67	Black, blue, orange	97	Red, black, blue, orange
8	Blue, green	38	Red, blue, green	68	Black, blue, green	98	Red, black, blue, green
9	Blue, brown	39	Red, blue, brown	69	Black, blue, brown	99	Red, black, blue, brown
10	Blue, slate	40	Red, blue, slate	70	Black, blue, slate	100	Red, black, blue, slate
11	Orange, white	41	Red, orange, white	71	Black, orange, white	101	Red, black, white
12	Orange, green	42	Red, orange, green	72	Black, orange, green		
13	Orange, brown	43	Red, orange, brown	73	Black, orange, brown		
14	Orange, slate	44	Red, orange, slate	74	Black, orange, slate		
15	Green, white	45	Red, green, white	75	Black, green, white		
16	Green, brown	46	Red, green, brown	76	Black, green, brown		
17	Green, slate	47	Red, green, slate	77	Black, green, slate		
18	Brown, white	48	Red, brown, white	78	Black, brown, white		
19	Brown, slate	49	Red, brown, slate	79	Black, brown, slate		
20	Slate, white	50	Red, slate, white	80	Black, slate, white		
21	White	51	Red, white				
22	Red						

wax has penetrated the cable at the butt and formed an effective seal against moisture. When completely waxed the cable is removed and the surplus wax is allowed to run off. It is important that the wax should be applied at the correct temperature. If the temperature is too low, then the wax does not penetrate the cable sufficiently, but excessive temperature, on the other hand, results in the wax becoming unfit for further use. A thermostatically controlled heater is the best means of wax heating and is usually employed on large construction jobs. Particular care must be taken to avoid the risk of fire when heating the wax.

TABLE VI

Composition of Some Common Types of Switchboard Cable

No. of Wires	External Diameter of Round Cable (in.)	Make up			Colours of Wires (See Table V)		
		Singles	Pairs	Triples	Singles	Pairs	Triples
6	0·3	—	3	—	—	21 + 1 to 21 + 3	—
12	0·3	—	6	—	—	21 + 1 to 21 + 6	—
20	0·38	—	10	—	—	21 + 1 to 21 + 10	—
31	0·4	1	—	10	101	—	21 + 1 + 31 to 21 + 10 + 40
41	0·43	1	20	—	101	21 + 1 to 21 + 20	—
60	0·51	—	—	20	—	—	21 + 1 + 31 to 21 + 20 + 50
61	0·51	1	—	20	101	—	21 + 1 + 31 to 21 + 20 + 50
80	0·6	—	40	—	—	22 + 31 to 22 + 50 21 + 1 to 21 + 20	—
100	0·68	—	20	20	—	22 + 1 to 22 + 20	21 + 1 + 31 to 21 + 20 + 50
150	0·82	—	—	50	—	—	21 + 1 + 31 to 21 + 20 + 50 22 + 1 + 31 to 22 + 20 + 50 51 + 1 + 31 to 51 + 10 + 40
200	0·95	—	100	—	—	22 + 31 to 22 + 50 22 + 61 to 22 + 80 21 + 1 to 21 + 20 21 + 31 to 21 + 50 21 + 61 to 21 + 80	—

Switchboard or Switchplate Wiring. The interconnexion of the various components on one mounting plate and the connexions between adjacent mounting plates is effected by individual wires. The most common type of wire for this purpose (known as *switchboard wire*) consists of a conductor of hard-drawn copper which is tinned and uniformly covered with two lappings of undyed natural Tussah silk or cellulose acetate rayon, and then one lapping of cotton is laid on in the alternate direction The whole insulated wire is thoroughly impregnated with beeswax. The gauge of wire most commonly used is 9·2 lb/mile (23 S.W.G.), although 6·4, 7·7, and 12·5 lb/mile conductors are occasionally used. Wire is available either as single conductors or as twisted pairs, and a range of colours similar to those of switchboard cable is provided.

In recent years a new type of insulated wire (*switchplate wire*) has been introduced for the internal wiring of relay groups and selectors in automatic exchanges. It has insulation qualities equal to the silk and cotton switchboard wire, but it is easier to handle than the latter. It is supplied in one gauge only, i.e. 6·4 lb/mile (25 S.W.G.), and the tinned conductor is lapped with undyed acetylated cotton with a final coarse braiding of the same material. The completed wire is then impregnated with beeswax. As in the case of switchboard wire a colour range is available and the same wire with the addition of a coating of enamel over the tinning is provided for use under humid conditions.

When the connexions between apparatus tags are very short, it is difficult to maintain the ordinary

covering of switchboard or switchplate wire even although the covering is waxed. In these circumstances bare tinned copper straps are used, and an insulating sleeve of the required colour is slipped over to provide a covering between the tags.

Double Silk and Cotton Braided Wire. For individual wires between apparatus racks a special insulation is required to avoid abrasion. Additional mechanical strength of the conductor itself is also required and for this purpose 20 S.W.G. (20·7 lb/mile) wire is normally used. The tinned conductor is provided with two lappings of silk and then closely braided with cotton, the complete wire being finally impregnated with beeswax. In some cases vulcanized indiarubber covered wire is used for inter-rack leads, but this type of wire is avoided wherever possible except when run in conduit on account of the inflammable nature of the wire.

Flameproof Jumper Wire. The temporary connexions on Main and Intermediate Distribution Frames are often referred to as *jumpers* and hence the wire used for this purpose is designated *jumper wire*. The wire must not only be mechanically strong and of good insulation resistance, but must also be easy to terminate and non-inflammable. In particular, the wire must be capable of withstanding a considerable amount of abrasion. The conductor is of tinned copper (20 or 22 S.W.G.) and is uniformly covered with a lapping of pure indiarubber. The rubber-covered conductor is next uniformly and tightly covered with a lapping of undyed wool, and then with an even and tight braiding of wool of the required colour. The braided wire is then treated with a flameproofing material and is available in the following colours and types:

One wire—White or red.

One pair—Blue and blue-red.

Three wire—Red, white, and green.

Four wire—Red, red-green, white, and green.

Cable Forms. It is important that the terminations of a switchboard cable or the internal wiring on an apparatus mounting plate should be arranged in a neat and orderly manner to facilitate maintenance. Moreover, some form of support, or other means to give rigidity, is desirable, and it is therefore usual to tie or lace together adjacent wires to form a solid and mechanically strong core. There are two recognized methods of wiring telephone equipment panels. The first, which is preferred by some manufacturers, consists of running the wires from tag to tag of the components on a mounting plate and then tying the wiring together at intervals with loops of waxed linen thread. If this system is adopted there is no great necessity to use different coloured wires for each connexion for, unless the wiring is very bulky, connexions can readily be traced during maintenance by shaking the conductor. If this is not possible it does not involve much work to undo the ties and to remake them afterwards. Other manufacturers prefer to make up a frame or board provided with pins or holes so located that the wiring can be laid out and firmly laced together to make a compact and rigid wiring form which is then transferred to the apparatus mounting plate where the ends of the form are terminated on the required tags. It is claimed for this method that the bulk of the wiring work can be carried out coincidently with the manufacture of the apparatus and that when a large number of units are involved the total labour costs for wiring are minimized. It will be apparent that the necessity for a rigid form requires that tight lacing should be adopted rather than loose ties. Moreover, a colour code is necessary in order that the wires can be correctly terminated and to allow of subsequent tracing of connexions during maintenance. A method of lacing is illustrated in Fig. 435. There are several variations of the knots used in lacing, but the essential requirement is to provide commencing and terminating knots which will not slip, and intermediate locking knots which lie snugly along the cable form. It is usual to provide intermediate knots at each point where the wires leave the form so that the connexions to the apparatus tags cannot readily be displaced. Fig. 436 shows a standard wiring frame for the termination of switchboard cables on switchboard jack strips. The board is designed with a clamping device for the jack strip and with a series of pins for the points where the wires are to leave the cable form. The length of wiring between the apparatus tag and the laced form is often known as the *skinner*. The wiring frame illustrated makes provision for various lengths of skinner to cater for different formations of multiple cables in manual switchboards.

Soldered Connexions. In telephony good electrical connexions are essential for, in normal circumstances, the complete circuit over which conversation takes place contains a large number of joints between cables and apparatus. Any one of these joints, if not efficient, introduces a variable resistance and thus becomes a source of noise and crackling which is particularly elusive and may persist for a long time before it is located. It is usual, therefore, to solder all connexions wherever possible and to exercise great care in the method and manner of soldering. The solder used is a lead-tin alloy of comparatively low melting point and is specified to be in accordance with Grade F of

British Standard Specification No. 219. For convenience of application to the small soldering tags of apparatus, etc., solder is supplied in the form of a thin tube (No. 13 or 16 S.W.G.), the centre of which is filled with resin. The resin acts as a "flux" during soldering operations by flowing over the parts to be jointed before they have reached an oxidizing temperature. Resin flux is used universally in the telephone industry in preference to corrosive fluxes which involve the risk of slow corrosive action and subsequent failure of the joint.

The tags and wires are normally coated with tin to facilitate soldering operations. It is important that the parts to be soldered together should be heated to a temperature not less than the melting point of the solder. If the temperature of the connexion tag is below the melting-point of the solder, a "dry" joint results. On the other hand, too high a temperature hardens the wire and makes it brittle, as well as possibly burning the insulation and so introducing the danger of contact between adjacent wires.

Cable Runs and Chases. It is important that a properly designed cabling scheme should be planned for all telephone exchanges. The route selected for cable runs should be such that the cables are not exposed to undue moisture or to the danger of mechanical damage. Moreover, the cable runs must be so designed that additional cables can be added to meet future growth of the exchange. Normally, switchboard cables are run on open ironwork racks above the apparatus units which they serve. Where cables must pass through a wall or floor the hole must be sealed with a fire-resisting material to prevent the spread of fire from one room to another. The most usual method is to fill the space round the switchboard cables with asbestos fibre and to close the entries to the holes by means of uralite or similar fire-resisting sheets. When it is necessary to run cables in floor or wall chases it is usual to employ lead covered cable. Here again, fireproof bulkheads are inserted at intervals if there is a danger of fire spreading via the chases.

The usual type of cable rack is made up of 1 in. or 1½ in. iron strip with riveted or welded crossbars at intervals of, say, 8 in. The cables are tied to the rack by means of lacing twine, and particular care is taken to avoid stresses on or abrasion of the cable at points where the cable rack changes its level. If necessary, the cable bearers are covered at such points with leather to prevent abrasion.

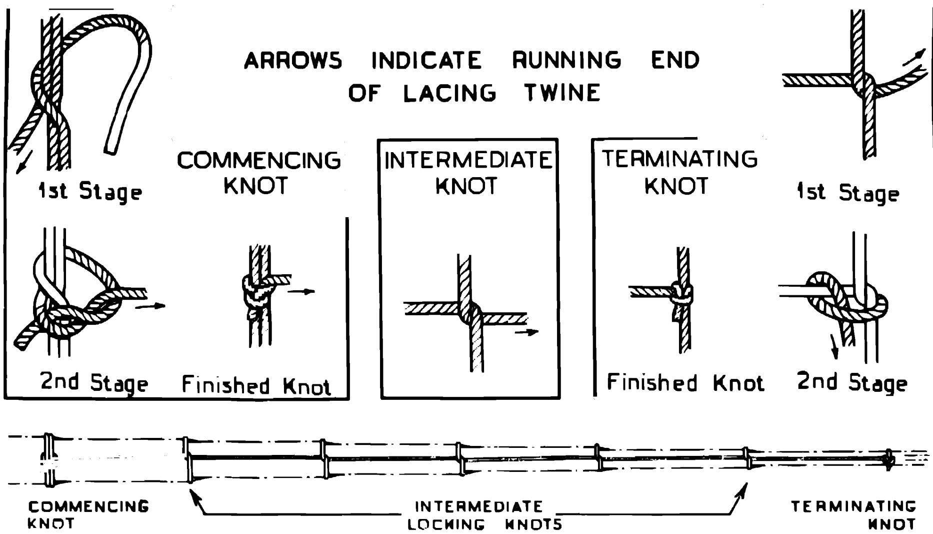
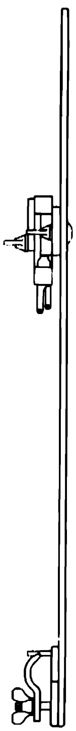


Fig. 435. Knots Used in Cable Lacing

Mounting of Apparatus. In the early days of telephony all the necessary signalling apparatus was accommodated inside the switchboard sections but, in the course of time, increased facilities and the complexities of providing communication between exchanges of various types, necessitated the external mounting of various components. At first, the additional apparatus to be provided was mounted in hardwood boxes known as *auxiliary units*. These units, which are similar in appearance to the old type of bell set (Fig. 216) were fixed to the walls of the switchroom and were cabled direct to the switchboard. On the introduction of the C.B. exchange with line relays and subscribers'

meters, a much more extensive system of apparatus racks became necessary.

The most common type of apparatus rack in manual exchanges consists of a structure of H-section iron uprights coupled by transverse angle-iron members at the top and bottom. The space between consecutive uprights is known as a *bay* and the apparatus is mounted on specially drilled mounting plates (Fig. 437) which are arranged horizontally in the bays. To avoid drilling the rack uprights for mounting plates of various sizes, the plates are commonly fixed by hook-bolts which clamp the units to the flanges of the uprights. The apparatus racks are of various heights to suit particular exchanges, but there has been some standardization of the bay width. The most usual width is $20\frac{1}{4}$ in. between uprights with mounting plates 19 in. wide. Another standard rack to take $22\frac{1}{2}$ in. mounting plates is also in fairly extensive use.



The apparatus is mounted on one side of the rack only. A wooden batten extends along most of the rear flange of the rack uprights and the cables to and from the apparatus are tied to these battens. Protection and mechanical rigidity of the wiring is obtained by the use of $\frac{1}{4}$ in. round stiffening bars behind the mounting plates. The stiffening bars are held by slots in the wood battens and the wiring is tightly laced to the bars (Fig. 438).

Apparatus racks entirely occupied by apparatus of the same type are given special descriptions, e.g. Line and Cut-off Relay Rack, Meter Rack, etc., but, in the past, the racks reserved for miscellaneous purposes were known as *Special Apparatus Racks*. The designation no doubt developed from the early days of C.B. working when any apparatus other than the subscribers' line relays and meters was of a "special" nature. The term "Special Apparatus Rack" is obsolete and any rack of this type is now more correctly designated a *Miscellaneous Apparatus Rack*.

Relay Sets. Modern junction terminations usually require upwards of six or eight relays together with condensers, resistors, and possibly transformers. There are, nevertheless, comparatively few external connexions to the equipment, and hence the circuits lend themselves to mounting as a unit which can be connected to the permanent wiring by means of a plug and jack. Such units are known as *relay sets* to distinguish from apparatus which is *strip mounted* and permanently connected to the cabling system. Apart from the subscribers' line and cut-off relays and a few special circuits, most modern exchange equipment is in relay set form. Relay sets have a number of advantages over the earlier system of mounting. In the first place the mounting and internal wiring costs are less, since a relay set can be assembled and wired in the factory rather than on site during the construction of an exchange. In addition, the relay set is much more convenient for maintenance since it can be removed from the apparatus rack for relay adjustment, etc. Apart from these obvious advantages, relay sets can be added or withdrawn from

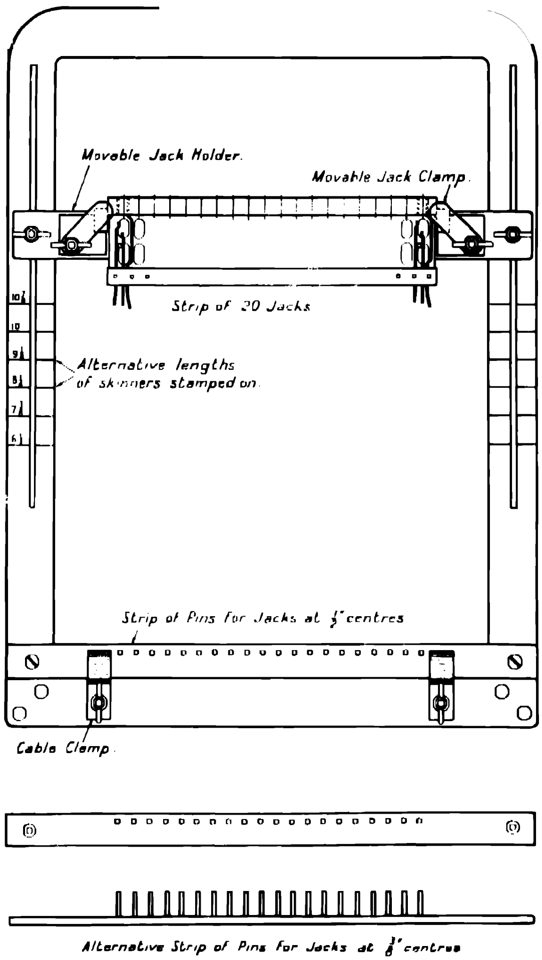


FIG. 436. WIRING FRAME FOR SWITCHBOARD JACKS

an exchange quickly and without the expenditure of much labour, which enables some appreciable economies to be made in the capital outlay of the exchange equipment. On the other hand, the introduction of a plug and jack does to some

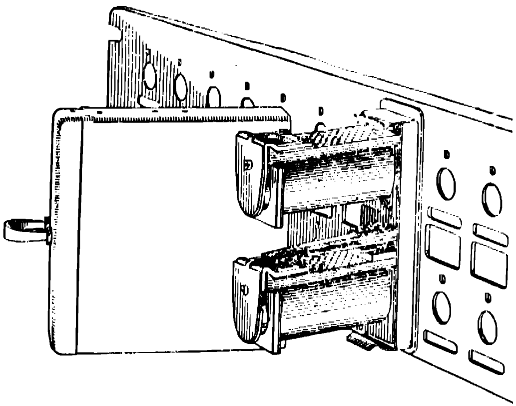


Fig. 437. Typical "Strip Mounted" Apparatus Plate

extent increase the fault liability of the circuits, but by careful design the increased fault liability is not appreciable.

Fig. 439 shows a typical relay set of a small type designed to accommodate up to ten relays. Much larger relay sets are available to cater for thirty or more relays. Generally there is only one circuit per relay set but, exceptionally, two or more circuits are mounted together. The relay set mounting plate is of pressed steel with holes and slots to accommodate the standard relay. Facilities are also available for the mounting of resistors, whilst condensers and other subsidiary apparatus may be mounted in a hinged condenser box at the rear of the mounting plate. Braided switchplate wire is generally used for the internal connexions of relay sets. The wiring is not laced but is tied as required to produce a neat and rigid wiring assembly. Coloured wires are not usually employed except for battery and earth connexions.

There are two types of shelf for the mounting of relay sets. The first consists of a pressed steel channel type shelf which is bolted to the uprights of the apparatus rack. The shelf is provided with slots to accommodate the bayonet type lugs of the relay plates and also mounts the shelf jack with which the relay set plug engages. There are two standard sizes of relay set plug, to give sixteen and thirty-two connexions respectively. Fig. 440 shows a cross-section of a channel type shelf of the pressed steel type. It will be noted that pins are provided at intervals in the rear of the shelf to carry the cables which serve the shelf jacks. A dust cover is also provided to give some degree of protection to the shelf wiring.

On the introduction of the Post Office standard automatic selector, a new type of mounting shelf was introduced. In order to obtain uniformity, the new type of shelf has also been adopted for the mounting of relay sets. The 2000-type shelf is a small rolled steel member of channel section and pressed steel cradles are attached to the shelf as required for the accommodation of relay sets. The 2000-type relay set is slightly different in design from the pre-2000-type illustrated in Fig. 440, but the same general principles of construction apply. Fig. 441 shows a cross-section of a 2000-type relay set shelf and the general outline of the new type of relay set. It will be noted that with the smaller relay sets the condenser box (when required) is arranged horizontally behind the relay set, but on the larger mounting plates the condenser box can

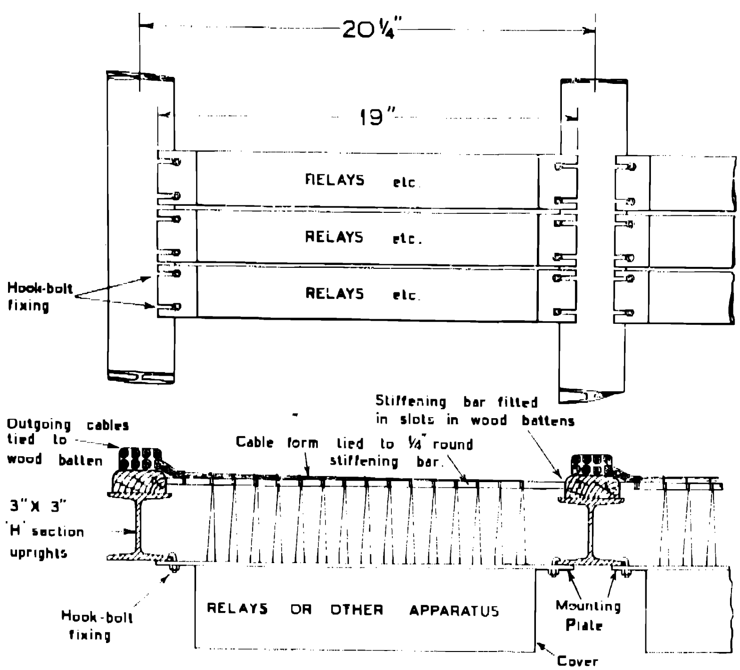


Fig. 438. Mounting and Cabling of Apparatus on Old Type Apparatus Rack

be placed in a vertical position behind the lower relays. All relay sets are provided with a tight-fitting dust cover. The cover of the pre-2000-type relay set is rounded at the front with finger grips, whereas the 2000-type relay set employs a square-fronted cover.

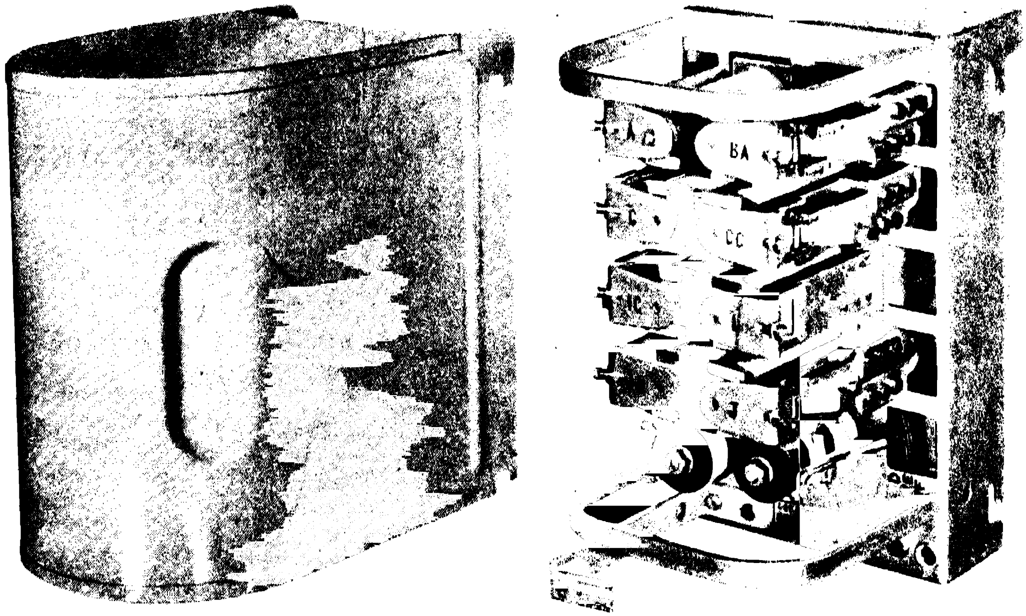


Fig. 439. Typical Relay Set with Cover Removed (Pre-2000 type.)

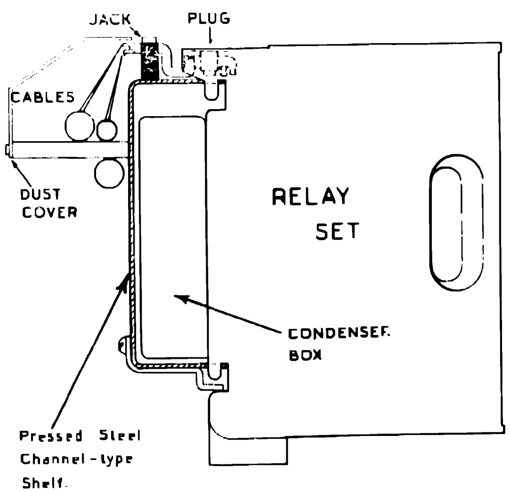


Fig. 440. Mounting and Wiring of Relay Sets on Channel-type Shelf

Standard Racks. All apparatus racks of a modern exchange are of the *single sided* or *open* type. The apparatus is mounted on one side of the rack only and all wiring and cabling is carried out from the rear, thereby obtaining the maximum accessibility for maintenance. Each rack is a self-contained unit accommodating its own local fusing on the left-hand vertical and its common equipment on the right-hand vertical. The relay sets and other

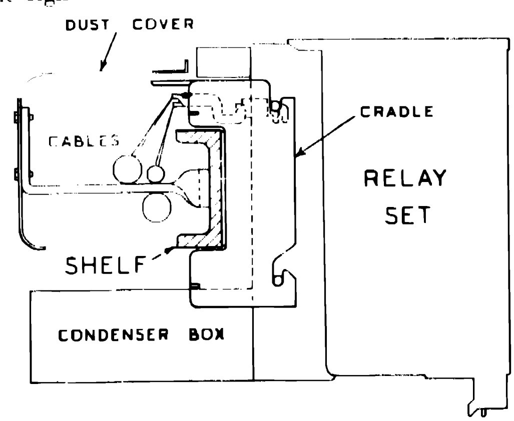
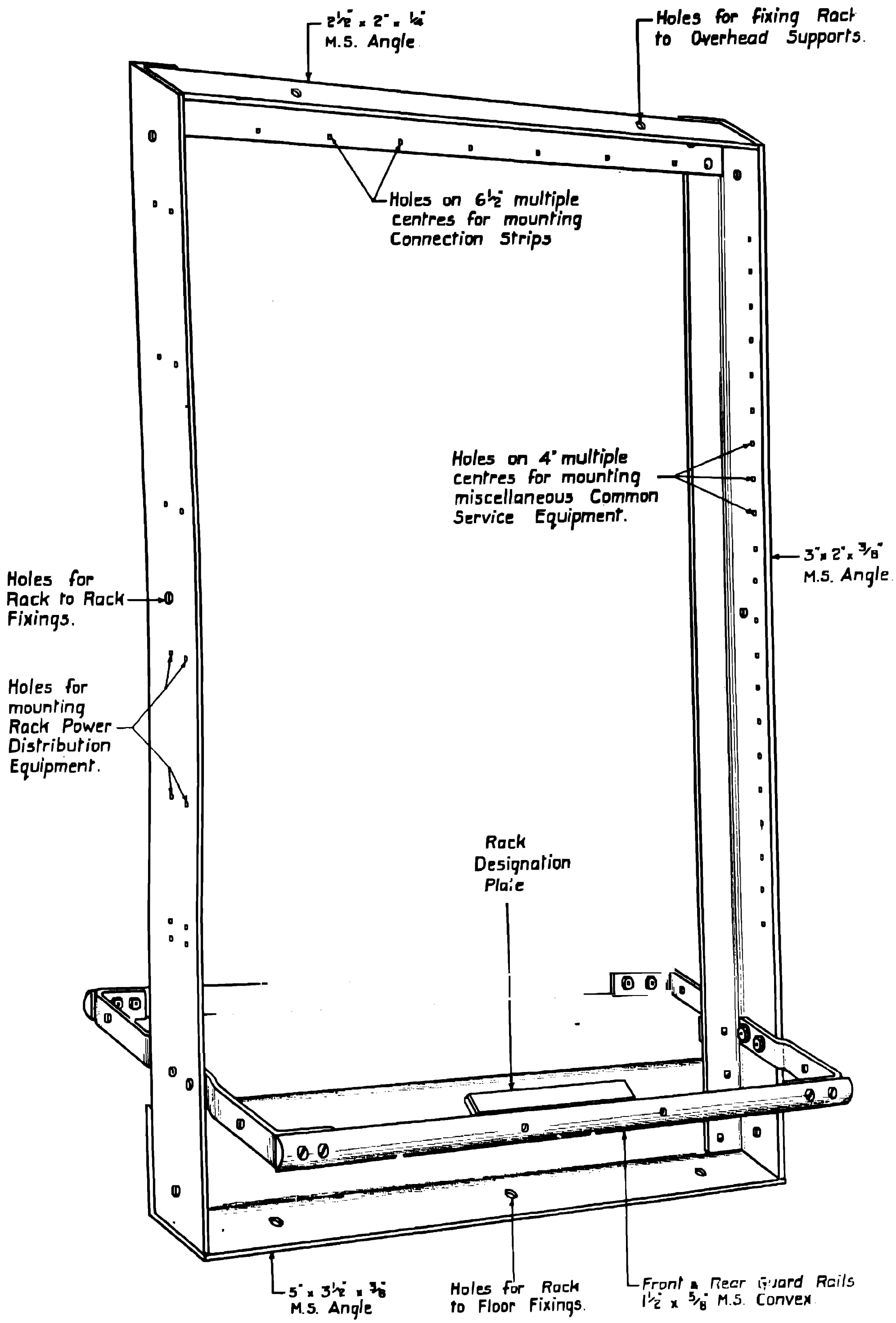


Fig. 441. Mounting and Wiring of 2000-type Relay Sets



Front View of Rack Framework

FIG. 442. CONSTRUCTION OF STANDARD APPARATUS RACK

equipment are accommodated on shelves fixed horizontally between the verticals.

Two heights of rack have been standardized:

10 ft 6½ in. for use in rooms with a minimum clear height of 12 ft.

8 ft 6½ in. for use in rooms with a minimum clear height of 10 ft.

There are four widths of racks known as types A, B, C, and D, viz:

Type	Width	No. of relay sets per shelf
	ft. in.	
A	4 6	10
B	3 6	7
C	2 9	5
D	1 6	2

The A type of rack is by far the most common, the narrower racks being usually employed for the mounting of miscellaneous apparatus, etc.

Rack Framework. Fig. 442 shows the general construction of the standard rack. The framework must be strong enough to carry not only the weight of the local apparatus and cabling but also the weight of the heavy overhead cable runs which are supported by the racks. The frame is therefore

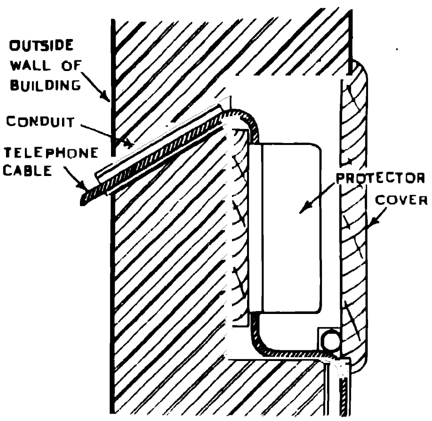


FIG. 443. CONCEALED LEAD-IN WITH OVERHEAD DISTRIBUTION

constructed of heavy rolled steel angle and the members are both riveted and welded at the corners. The equipment shelves are bolted to the 2 in. flange of the uprights, the fixing holes being made as required to suit the quantity and type of equipment. The 3 in. flange of the rack upright members are provided with a series of universal drillings which minimize drilling on site and enable the common apparatus and power distribution to be mounted in a uniform manner. The rear of the top angle is also drilled in the same way to accommodate various connexion strips for common services. Guard rails are fitted to both the front

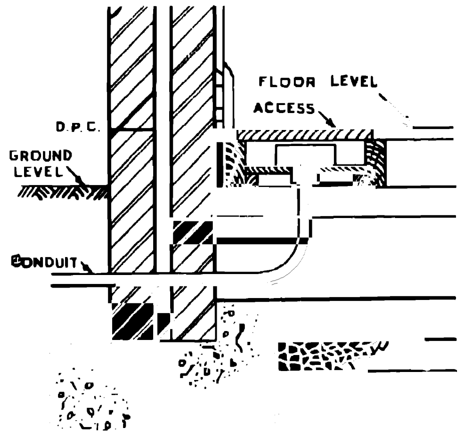


FIG. 444. CONCEALED LEAD-IN WITH UNDERGROUND DISTRIBUTION

and rear of the rack at a standard height of 6 in. from the floor. These guard rails project slightly beyond the face of the equipment and the wiring, and protect against possible damage by travelling ladders, etc. A rack designation plate, on which the type and number of the rack is signwritten, is mounted on the front guard rail.

Wiring of Subscribers' Premises. The wiring requirements of subscribers' premises differ from those of telephone exchanges in several respects. Possibly the most important requirement is that the wiring shall harmonize with the colour scheme and shall be as inconspicuous as possible. The wiring must also be capable of working satisfactorily in damp situations or at least in conditions of higher relative humidity than telephone exchanges. The latest type of cable for use in normal situations consists of 12½ lb tinned copper conductors insulated with vulcanized rubber which is coloured for identification purposes. The rubber insulated wires are then enclosed in a cotton braiding which can be easily slipped back to expose the ends of the conductors. Brown and cream braidings are available to match the colour schemes of the rooms in which they are employed. The cable is available in various small sizes containing from one pair to four or more wires. In particularly damp situations a lead-covered cable is available in which the conductors are enamelled, cotton covered and impregnated with paraffin or a similar wax. A special form of flat three-wire cable

has been introduced for use in rooms with carpet covered floors where a telephone is required on a desk or table situated away from the wall. The cable consists of three tinned copper conductors laid parallel and covered with coloured vulcanized rubber, the whole being completely enclosed in a flat moulded brown rough rubber sheath. The width of the cable is approximately 1 in. whilst the thickness is in the order of $\frac{1}{8}$ in.

Concealed Wiring. It is probable that in the near future more consideration will be given to the provision of facilities for telephone wiring, etc., in the design and construction of dwelling houses. The method adopted in any particular instance must, of course, depend upon the type of property and the structural design. One of the more promising schemes is the provision of a cableway behind detachable skirting boards in all rooms, halls and passages, with ducts or conduits under the floor across all doorways and through intervening walls. As an alternative to this arrangement special ducts may be provided in all walls at, say 9 in. above the floor level. This duct could be covered with a plastic moulding or similar material. In the larger buildings special ducts under the floor may be found more suitable. Where an inexpensive scheme is required for smaller dwellings, facilities for a limited amount of cabling can be provided by the use of deeply-grooved picture rails with short lengths of conduit through the dividing walls.

A considerable improvement can be made by the provision of a conduit for leading-in the external wiring and by providing concealed accommodation for the protector. Figs. 443 and 444 indicate possible schemes for use when the distribution is overhead and underground respectively.

EXERCISES XIV

1. Discuss how lightning and power lines may produce dangerous conditions in a telephone system.

2. What measures are commonly adopted to protect overhead and underground lines, exchange and subscribers' equipment from damage by lightning and power induction? (*C. & G. Transmission and Lines, Grade I*, 1942.)

3. Using a sectional sketch, describe the construction of a heat coil of the earthing type. Enumerate the factors that influence the rise of temperature in the coil when a current passes through it, and state the conditions under which operation occurs. Explain why heat coils as well as fuses are provided between the line cables and the apparatus at a telephone exchange. (*C. & G. Telephony, Grade I*, 1943.)

4. Explain the purpose of the M.D.F. and the I.D.F. at a telephone exchange. Can you suggest any means of avoiding the use of an I.D.F. for subscribers lines?

5. Describe a modern form of lightning protector. What are the advantages and limitations of gas discharge protectors?

6. Sketch and describe typical arrangements for leading in and terminating the cables at a large exchange. (*C. & G. Transmission and Lines, Grade I*, 1940.)

7. How does the resistance of an earth electrode depend upon its buried length? Describe a typical earthing system for a large exchange.

8. Describe the construction of a switchboard cable. What precautions are taken to avoid interference between the circuits in a switchboard cable?

9. Explain how switchboard cables are terminated on an apparatus rack. Describe, particularly, how:

   (*a*) moisture is excluded from the open wires at the cable end;

   (*b*) the wiring is given mechanical rigidity and an orderly lay-out.

10. Describe the methods of mounting relays and other apparatus in manual and automatic exchanges.

CHAPTER XV

MAGNETO AND C.B.S. EXCHANGES

The Magneto System. Owing to the various disabilities which will have been apparent from the consideration of previous chapters, the magneto system is now obsolete for all new exchange work in this country. There are, nevertheless, some thousands of subscribers in the British Isles connected to exchanges of the magneto type, and although it must be admitted that this number will decrease rapidly during the next few years as a result of the policy of automatization, it is nevertheless considered desirable to review the main circuits in this volume. The magneto system has certain merits which commend its retention under suitable colonial and foreign conditions. Where it is not practicable to provide lines of the requisite standard of insulation and ohmic resistance for the adoption of C.B.S. or C.B. working, the magneto system is still probably one of the most practicable methods of signalling.

The magneto system, as its name implies, is characterized by the use, for signalling, of low-frequency alternating current produced by means of magneto generators. The system is also a local battery system in that the current for the energization of the subscriber's transmitter is derived from a primary battery situated at the subscriber's premises.

Condensered and Non-condensered Exchanges. Basically, in a magneto system, no direct current is used for signalling purposes, and hence in the original system there was no objection to the introduction of bridging apparatus across the *A*- and *B*-lines, which, whilst having the necessary high impedance to speech, offered a comparatively low ohmic resistance to any direct current. The advent of such automatic signalling systems as the C.B.S. and C.B. systems made it desirable that an operator, say at a C.B. exchange, should have the same supervisory conditions when she called a magneto subscriber on a nearby exchange as when she called a number on a similarly adjacent C.B. or C.B.S. exchange. In order to obtain this facility it was necessary not only to modify every magneto instrument to give a disconnexion to direct current when the receiver was replaced, but also to remove any d.c. bridging apparatus from the exchange equipment. The d.c. signalling requirements for junction working must not of course interfere with the fundamental magneto signalling, and the conditions are met by the insertion of 2 μF condensers in the subscriber's bell circuit and also in series with the bridging indicator or other apparatus at the exchange. The condensers give an effective block to direct current, but their value is such that the impedance of the circuits to generator ringing is not appreciably increased.

As the number of C.B.S. and C.B. exchanges grew, more and more magneto areas were condensered to give automatic signalling facilities on junction calls, but the process was slow until the introduction of Trunk Demand working in 1932. The Trunk Demand system necessitates the accurate timing of all calls without the continual supervision of the trunk operator, and the clearing signal from the calling subscriber's switch-hook is therefore used for the control of the timing device at the trunk exchange. All magneto exchanges are now converted to the condensered arrangement and the circuits considered in this chapter are all of the condensered type.

Operating Procedure. Before considering the electrical connexions, it is desirable to be clear as to the method of operating a magneto switchboard:

1. The originating subscriber turns the handle of his magneto generator, thus dropping the shutter of his calling indicator at the exchange.

2. The operator takes the answering plug of a pair of cords and inserts it in the jack of the calling subscriber. The operator also restores the shutter of the calling indicator and places the speaking key associated with the answering plug in the speaking position and ascertains the number required.

3. The operator inserts the calling plug of the pair in the jack of the subscriber required and with the aid of the ringing key calls the wanted subscriber with the switchboard generator. In multiple type exchanges the operator taps the tip of the calling plug on the bush of the required multiple jack in order to test for the engaged condition before she completes the connexion.

4. On gaining the attention of the called subscriber, the operator restores the speaking key to the normal position. Both subscribers are now in communication.

5. At the end of the conversation, the subscribers hang up their receivers and "ring off" (i.e. give several turns on the generator), thereby dropping the clearing indicator in the cord circuit.

6. On receipt of the clearing signal the operator removes both plugs and restores the cord circuit indicator.

Subscribers' registers or meters are not provided in magneto exchanges and the operator records details of each call on a ticket.

Non-multiple Exchanges. Apart from a number of very small wall type switchboards, the majority of the remaining public exchanges are made up of one or more standard 50- or 100-line switchboard sections. Both these switchboards are of the floor pattern, the 100-line switchboard being illustrated in Fig. 445. In common with other magneto boards, the 100-line section is somewhat different from the usual switchboard design in that the plugshelf is dissociated from the keyshelf and is placed above the calling indicators. By this means the cords do not cross the indicator field and do not therefore interfere with the action of or obscure the indicators.

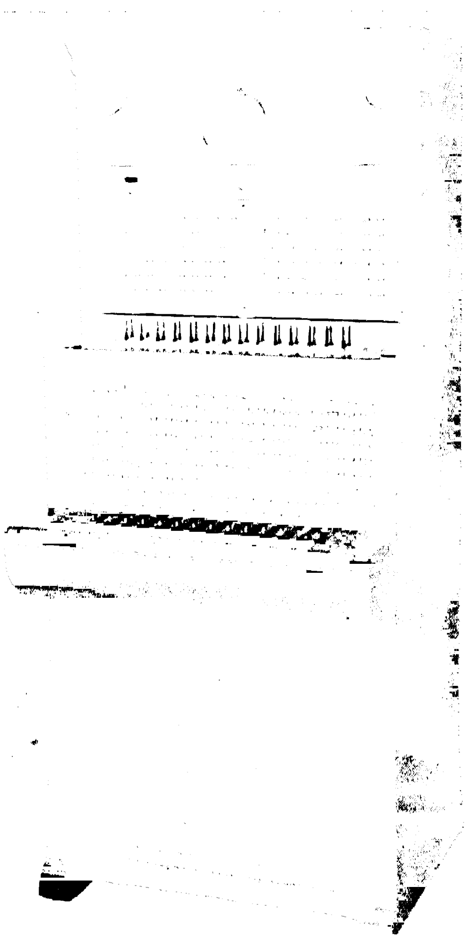


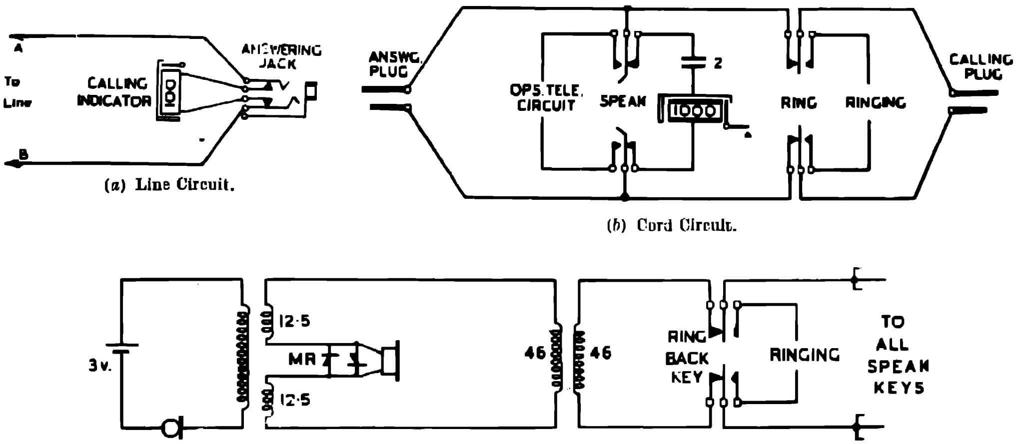
FIG. 445. 100-LINE MAGNETO SWITCHBOARD

Provision is made in the two panels for 100 subscribers' jacks and twenty junction jacks, all in strips of ten jacks. The indicators are arranged in rows of twenty, the bottom row being reserved for the cord circuit ring-off indicators. Accommodation is provided for a maximum of eighteen cord circuits, although the number of circuits actually fitted depends on the amount of traffic to be handled. The subscribers' indicators are of the two-coil type (Fig. 161) wound to a resistance of 100 Ω. The ring-off indicators associated with the cord circuits are of 1000 Ω resistance and are of the high-impedance type (Fig. 162).

Line, Cord, and Operators' Circuits. The main circuits of a non-multiple magneto switchboard are shown in Fig. 446. Each subscriber's line is terminated on the outer springs of a five-point jack, the inner springs of which are wired to the calling indicator.

The ringing and speaking keys of the cord circuit are combined as one double-throw lever key designed so that it is locking in the speaking position and non-locking in the ringing position. The ring-off indicator has a 2 μF condenser in series and is normally connected across the tip and ring conductors in order that it can receive the clearing ring from either subscriber. The circuit is arranged so that the ring-off indicator is disconnected when the speaking key is thrown in order to prevent its false operation when the operator wishes to ring back the calling subscriber. The 2 μF condenser in series with the indicator avoids interference with the d.c. supervisory condition given when the subscriber replaces his receiver and a condensered magneto cord circuit may therefore be said to have *through clearing* in either direction.

In small exchanges of the type under consideration, it is usual to provide primary cells for the operator's telephone circuit. The primary circuit is closed by the insertion of the operator's instrument plug into the jack provided in the lock rail of the switchboard. The receiver is fitted with copper-oxide rectifiers to prevent acoustic shocks (see Chapter V), and together with the secondary windings of the induction coil, is isolated from the cord circuits by the transformer which is provided solely to guard against any d.c. potentials which might otherwise be applied to the rectifiers. The commons from the cord circuit speaking keys are taken to the telephone circuit via a non-locking plunger type "ring-back" key. One ring-back key is provided per position so that the operator can, by throwing the speaking key and depressing the ring-back key, ring the calling subscriber should



(*a*) Line Circuit.

(*b*) Cord Circuit.

(*c*) Operator's Telephone Circuit.

Fig. 446. Circuits of Non-multiple Magneto Switchboard

he leave the telephone whilst a call is being set up.

Multiple Type Exchanges. Various types of multiple switchboard have been produced from time to time, but the three-position, five-panel section is probably the most common. The face equipment of such a section is illustrated in Fig. 447 and shows a panel capacity for twenty-two jack or designation strips in the answering and outgoing junction portion of the field, together with twenty-five strips of multiple jacks. The subscribers' multiple jacks are in strips of twenty, and there is

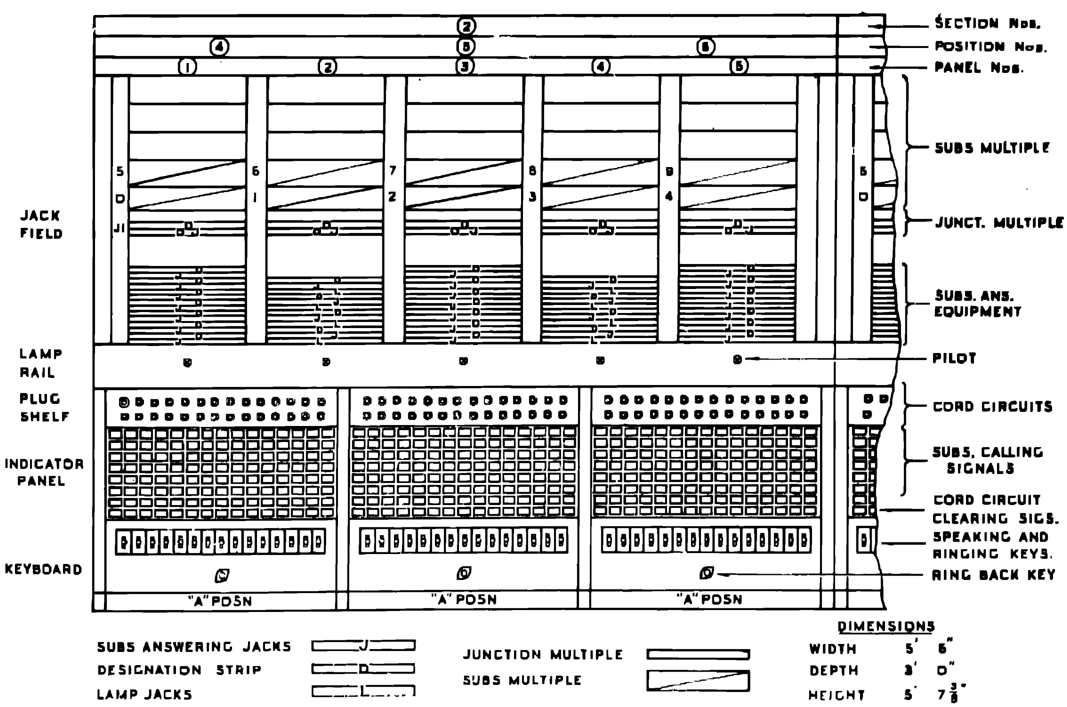
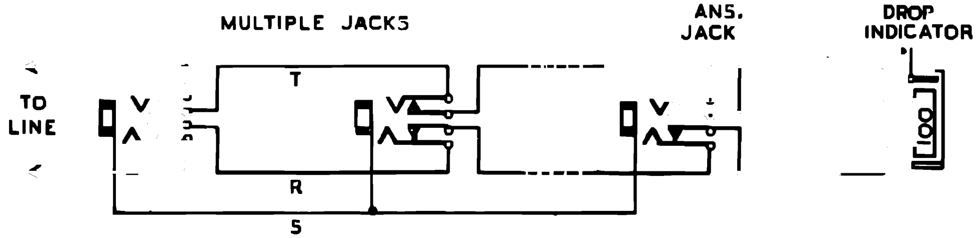
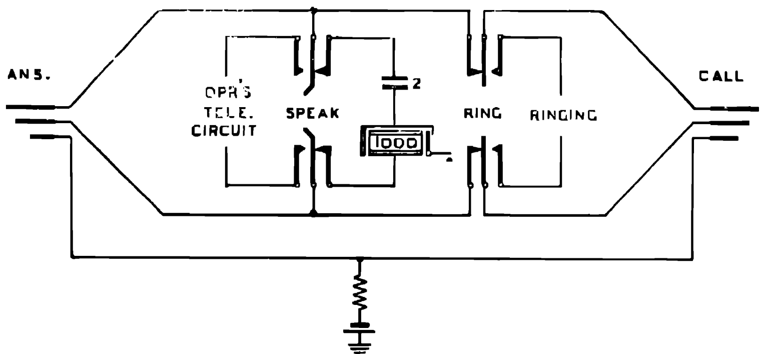


Fig. 447. Typical Face Equipment of Multiple-type Magneto Switchboard

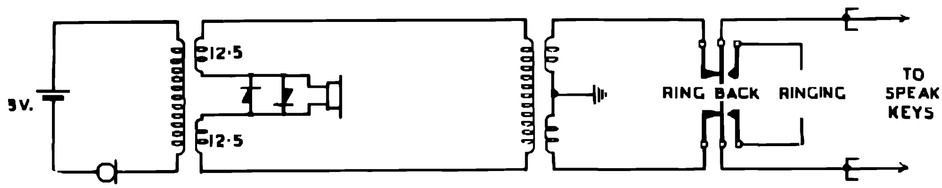
therefore a capacity for 2500 lines with the usual five panel multiple. The outgoing junction multiple usually recurs once every three or four panels. The plugshelf is provided with capacity for fifteen cord circuits, and the lay-out of the keyshelf and the general design of the section is somewhat similar to that of the 100-line switchboard. The latter type section can, incidentally, be adapted for multiple working by the provision of multiple jacks above the normal answering jacks, and is often used for exchanges up to a maximum of 800 lines.



(a) Line Circuit.



(b) Cord Circuit.



(c) Operator's Telephone Circuit.

Fig. 448. Circuits of Multiple-type Magneto Switchboard

The line circuit (Fig. 448 (a)) employs five-point break jacks arranged as a series multiple. The bushes of all jacks are commoned and the engaged test condition is applied from the cord circuit. Certain exchanges have been installed in which the engaged test battery is applied to the bushes of all jacks by the operation of auxiliary springs on the insertion of a plug. This arrangement is however comparatively rare and is not so satisfactory as the arrangement shown. The cord circuit is similar to that of the non-multiple exchange, but has a third (sleeve) conductor connected to battery via a suitable resistance or impedance coil. The operator's telephone is also similar to that already considered, but with an additional earth connexion at the centre point of the isolating transformer. When the operator taps the tip of a calling plug on the bush of an engaged jack, the battery potential existing on the bush causes a momentary current to flow via one winding of the transformer to the earth in the centre. The surge of current produces an e.m.f. in the secondary circuit, the resultant current of which gives the engaged click in the operator's receiver. In order that the impedance of the A- and B-lines to earth shall be the same, it is essential that the earth connexion in the operator's telephone circuit should be connected to both lines as shown.

Junction Working. Inter-communication between magneto exchanges can be provided with junctions arranged for magneto signalling. Such a method is however used only when direct current

signalling is impracticable due to the resistance of the junction lines. Ordinarily, C.B. signalling is adopted between exchanges since it gives not only automatic calling whenever a plug is inserted into an outgoing junction jack, but can also be arranged to provide a supervisory signal when the distant operator and subscriber answer. Various methods of operating junctions have been devised from time to time, but since these methods are generally adaptations of the arrangements designed for use between C.B. exchanges, it is proposed only to deal with several of the more common schemes in this chapter.

Outgoing Junction C.B. Signalling. An outgoing junction using C.B. signalling is illustrated in Fig. 449. The outgoing jacks are of course multipled throughout the exchange, and on the insertion of a calling plug battery via *IC* is sent out over the *B*-line by the operation of the auxiliary jack springs. This battery operates the calling relay or indicator at the distant exchange and, when the operator answers, a similar battery is returned over the *A*-wire to the magneto exchange. Relay *L* is operated by the supervisory battery, and at contact *L*1 returns a loop via *IL* to give a supervisory condition should the call originate from a C.B. or C.B.S. exchange. An impedance coil *I*, together with the 2 μF condenser *QA*, are provided to ensure a good balance between the *A*- and *B*-lines

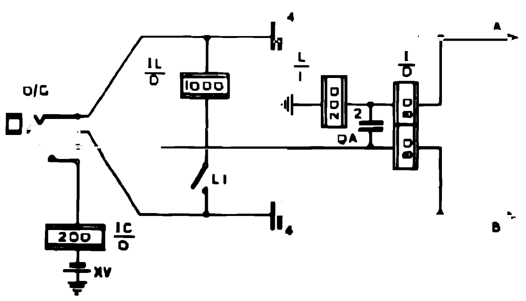


FIG. 449. OUTGOING JUNCTION WITH C.B. SIGNALLING

and their insertion avoids the necessity of providing a well-balanced combination for relay *L* and impedance *IC*. Where the junction is outgoing to a C.B. exchange, a supervisory lamp is often provided at the magneto exchange to give an indication when the distant C.B. operator and subscriber answer. Under these conditions *IC* is provided with a make contact, and relay *L* has an additional break contact. The two contacts are connected in series so that the supervisory lamp glows when the plug is first inserted in the outgoing jack, and is dimmed when relay *L* operates on receipt of a supervisory battery on the *A*-wire.

Incoming Junction C.B. Signalling. Fig. 450 is a representative circuit of an incoming junction arranged for C.B. signalling. The battery on the *B*-wire received from the distant exchange operates

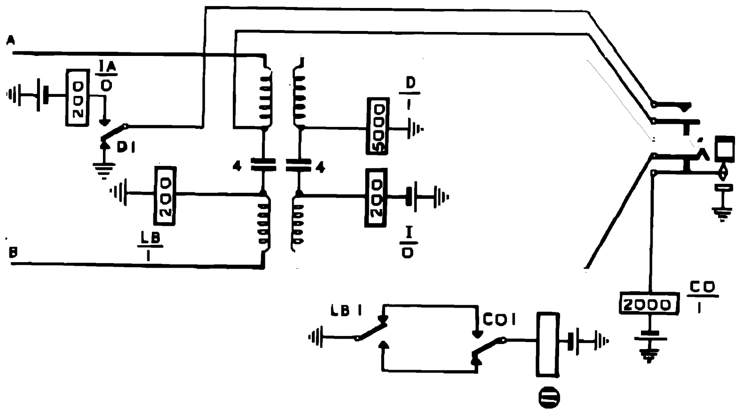


FIG. 450. INCOMING C.B. SIGNALLING JUNCTION

relay *LB* whilst *LB*1 energizes the calling indicator or relay. When the operator inserts an answering plug, relay *CO* is operated by the auxiliary springs of the incoming jack and **CO1** disconnects the calling indicator. The operator now throws her speak key and the telephone loop operates relay *D* from the battery supplied at *I*. *D*1 applies battery via *IA* and the auxiliary jack springs to the *A*-line in order to give a supervisory signal to the originating exchange. When the call is extended, the called subscriber's loop again operates *D* to provide through supervisory conditions. At the termination of the conversation, relay *LB* is released by the withdrawal of the plug at the distant exchange, and the calling indicator is re-operated at *LB*1 until such time as the incoming operator releases *CO* by the withdrawal of her plug from the incoming jack. This circuit can be used in conjunction with the outgoing circuit given in Fig. 449 to make a bothway junction if arrangements are made to engage all outgoing jacks when an incoming call is in progress. The engaged test conditions can be provided by additional make contacts on the *LB* and *CO* relays which can be connected in parallel to apply the engaged test battery to the outgoing multiple. The *LB* contact ensures that the outgoing multiple is engaged as soon as the circuit is seized for an incoming call, and the *CO* contact similarly guards against intrusion until the plug

is withdrawn from the incoming jack at the termination of the call.

Calls from Adjacent Automatic Exchanges. Under present-day conditions magneto exchanges are often in close proximity to one or more automatic exchanges. Under these circumstances it is possible to provide direct access to the magneto exchange from the selector levels at the automatic exchange. On calls incoming from a selector level, the normal incoming circuit (Fig. 450) must be slightly modified in order to prevent the seizure of a junction from the outgoing end before the circuit at the magneto exchange has been restored to normal after the previous call. Additional *LB* change-over contacts are connected in the *A*-wire signalling circuit as shown in Fig. 451. Hence, when the circuit is released at the end of a call, relay *LB* is de-energized and at *LB*2 replaces the supervisory battery by full earth. (If the called subscriber clears first, the earth is already applied at *D*1.) The outgoing relay set at the automatic exchange is arranged so that after the release of the switches, the junction is re-engaged until the earth on the

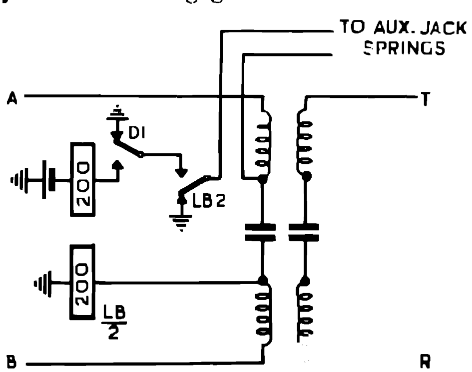


FIG. 451. MODIFICATIONS OF CIRCUIT INCOMING FROM AUTOMATIC EXCHANGE

A wire is removed, i.e. when the magneto operator withdraws the plug from the incoming jack.

The incoming circuit already considered gives full supervisory facilities and at first sight appears suitable as an automatic metering circuit on calls dialled by automatic subscribers. There are, however, certain difficulties, one of the most important being the possibility of false metering due to the short-circuiting of the tip and ring of the calling plug when it is inserted into a jack. To overcome these defects a circuit in which metering is under the control of a special meter key is used. (Fig.

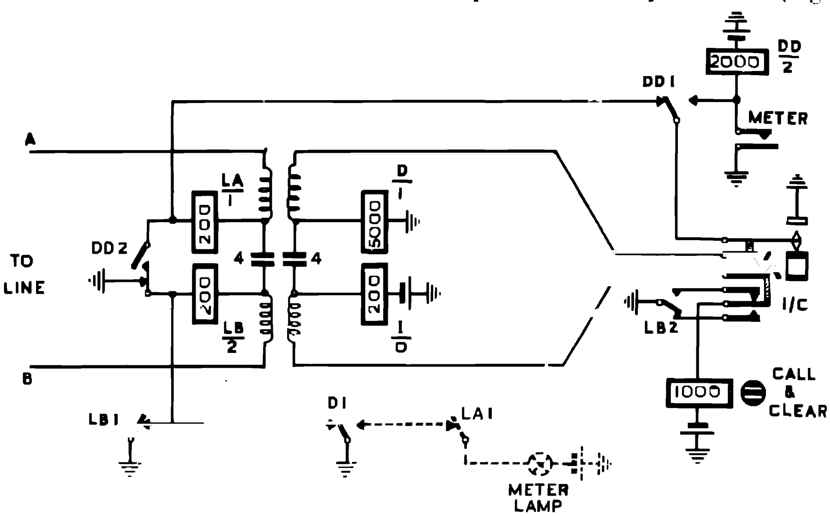


FIG. 452. CIRCUIT INCOMING FROM AUTOMATIC EXCHANGE
With metering under control of operator.

452). The battery on the *B*-wire operates *LB* as before, and contact **LB2** energizes the calling indicator. **LB1** is not effective at this stage. When the operator answers, the insertion of a plug into the incoming jack operates the auxiliary springs and disconnects the calling indicator. The operator establishes the connexion required and then depresses the plunger type meter key which prepares the metering circuit in readiness for the return of metering conditions when the called subscriber answers.

Relay *DD* is operated by the depression of the meter key and at **DD1** is held to the earth on the auxiliary jack springs for the duration of the call. **DD2**, which is a make-before-break to avoid clicks, removes one of the earth connexions from the *LB* relay and loops the incoming *A*- and *B*-wires together via the repeating coil and relays *LA* and *LB* in series. In due course the called subscriber answers and, by looping his line, allows *D* to operate from the battery supplied via *I*. **D1** removes the only remaining earth from *LA* and *LB*, so allowing the incoming battery on the *B*-wire to be returned via *LA* and *LB* to the originating auto exchange over the *A*-wire, thus effecting metering against the calling subscriber. At the termination of the conversation *D* releases when the called subscriber hangs up and *D*1, by applying earth to

the A-wire, repeats the clear to the automatic exchange. The calling subscriber in replacing his receiver releases the automatic switches and removes the battery from the B-wire. $LB2$ in releasing, operates the clearing indicator which remains energized until the auxiliary jack springs change over on the withdrawal of the plug. The removal of the plug also releases DD and the circuit is restored to normal. Contacts $LB1$ and $D1$ ensure that an earth is applied to the A-wire immediately either the calling or called subscribers clear. This earth is maintained in order to engage the outgoing junction at the automatic exchange from re-seizure until the call is cleared at the magneto exchange by the withdrawal of the plug (i.e. until relay DD is released).

It has already been stated that, with any circuit which provides for automatic registration, it is important to avoid any possibility of false metering. From an examination of the normal operator's telephone circuit (Fig. 448) in conjunction with the incoming circuit (Fig. 452) it will be apparent that a failure of the earth in the former circuit would produce false registration if the operator threw the speaking key at any time between the operation of the meter key and the called subscriber answering. On positions where circuits incoming from automatic exchanges are terminated, it is therefore desirable to modify the operator's telephone circuit to prevent the possible operation of relay D when the speaking key is thrown. Fig. 453 illustrates the arrangements adopted. The d.c. loop is broken by the 2 μF condenser QC, but provision is made for the engaged test by the addition of QA and YA in parallel. Normally QA is devoid of charge due to the effect of resistance YA, but when the tip of the plug encounters battery potential on the bush of an engaged jack, a current surge to charge the condenser traverses the transformer winding and thus produces the required click. Any resulting potentials on the condensers are slowly dissipated by YA which is, of course, of sufficiently high resistance to prevent interference with the signalling arrangements. As usual, QB and YB are provided to maintain the balance of the two lines.

Joint Access. So far it has been assumed that the junctions have been used solely by the automatic subscribers. More often than not, however, the same group of junctions must carry traffic from manual exchange operators who obtain access to the magneto exchange via the selectors at the automatic exchange. If the circuits are arranged for automatic registration, it follows that no supervisory signal is returned to the automatic exchange until the called subscriber answers—no indication being given when the magneto operator answers. On manual-to-manual calls, the return of supervisory conditions when the incoming operator answers is highly desirable but, unless elaborate arrangements are made for differentiation, it is not possible to cater for these two divergent facilities. It is however often the case that a magneto operator may deal with traffic from other manual exchanges (over separate and direct junctions) in addition to the traffic via an automatic area. In these circumstances it is usual to retain the normal (i.e. non-condensered) operator's circuit in order to give key supervision on the manual routes and to make special arrangements on those circuits incoming from an automatic exchange.

The circuits carrying joint traffic from automatic subscribers and manual exchange operators are

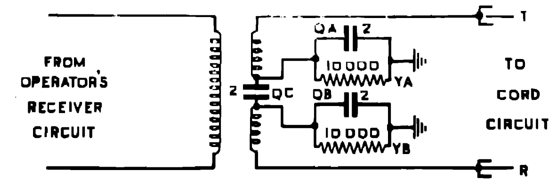


FIG. 453. MODIFICATIONS TO ENGAGED TEST CIRCUIT TO AVOID POSSIBILITY OF FALSE METERING

provided with the meter lamp and associated connexions shown dotted in Fig. 452. On the establishment of an incoming call, the magneto operator does not depress the meter key at once and she can therefore enter the circuits without danger of false metering. When the called subscriber answers, **D1** lights the meter lamp and the operator then depresses the meter key to return the metering condition to the automatic exchange. The operation of LA when the battery is returned on the A-wire dims the meter lamp, thereby indicating that metering has been effective.

The outgoing and incoming circuits considered can be, and in fact usually are, worked on a bothway basis, but the arrangements for associating the incoming and outgoing parts are largely a question of applying the engaged condition on the outgoing multiple when the circuit is in use for an incoming call. In the interests of simplicity the coupling arrangements for bothway working have not been shown.

Dialling to Automatic Exchanges. Calls from a magneto exchange to the subscribers in nearby automatic areas are, wherever possible, dialled direct by the magneto operators. Each position at the magneto exchange is provided with a dial and the ideal arrangement would be such that the dial could be associated with any cord circuit as required by the operation of a key. This arrangement is used in some C.B.S. exchanges and in all

C.B. exchanges, but the circuit conditions at a magneto exchange make the adoption of this method difficult. As will have been seen from the diagrams already considered, all incoming and out-

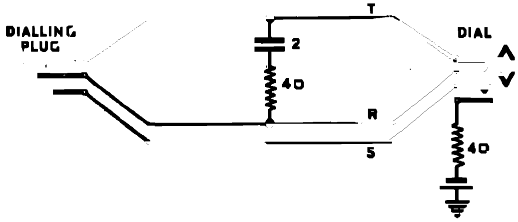


FIG. 454. CONNEXIONS OF DIALLING PLUG

going junctions at a magneto exchange must be fitted with a transmission bridge in order to segregate the C.B. signalling on the junction proper from the normal circuit conditions of the cord circuit. Due to the presence of this bridge in all outgoing circuits it is not easy to associate the dial with the cord circuit, and a special jack per junction is provided to obtain access, for dialling purposes, to the metallic conductors of the line. In all except single position magneto positions, the connexions from the dial are terminated on a special dialling plug which the operator must insert into the dialling jack of an outgoing junction in order to set up any call to an automatic exchange. The connexions of the dialling plug are illustrated in Fig. 454. The 2 μF condenser and 40 Ω resistance are connected across the impulsing contacts to act as a spark quench combination, and off-normal springs of the dial are used to supply a battery via the sleeve of the dialling circuit. At small one-position exchanges the number of junctions is usually comparatively small, and it is better to provide a dialling key per junction rather than a dialling jack and the common dialling plug. The connexions of the dialling key are identical with those of the dialling plug.

Loop Dialling. Normally, loop dialling is employed and the circuit arrangements at the magneto exchange are shown in Fig. 455. The circuit is designed for use if required in conjunction with the incoming equipment given in Fig. 452 to form a bothway junction. On receipt of a demand for a call to the automatic area, the operator inserts the calling plug into the outgoing jack after testing for the engaged condition. Relay *CO* operates from battery supplied via a 120 Ω resistor and the auxiliary jack springs. *CO1* and *CO2* disconnect the incoming equipment (if fitted) and connect relays *LA* and *LB* to the *A*- and *B*-lines respectively. The incoming selector at the automatic exchange is seized by the earth on the *B*-wire from relay *LB*. *CO3* completes a holding circuit for *CO* under the control of *R2* in order to maintain the incoming equipment clear of the line until the automatic exchange switches are released at the end of a call.

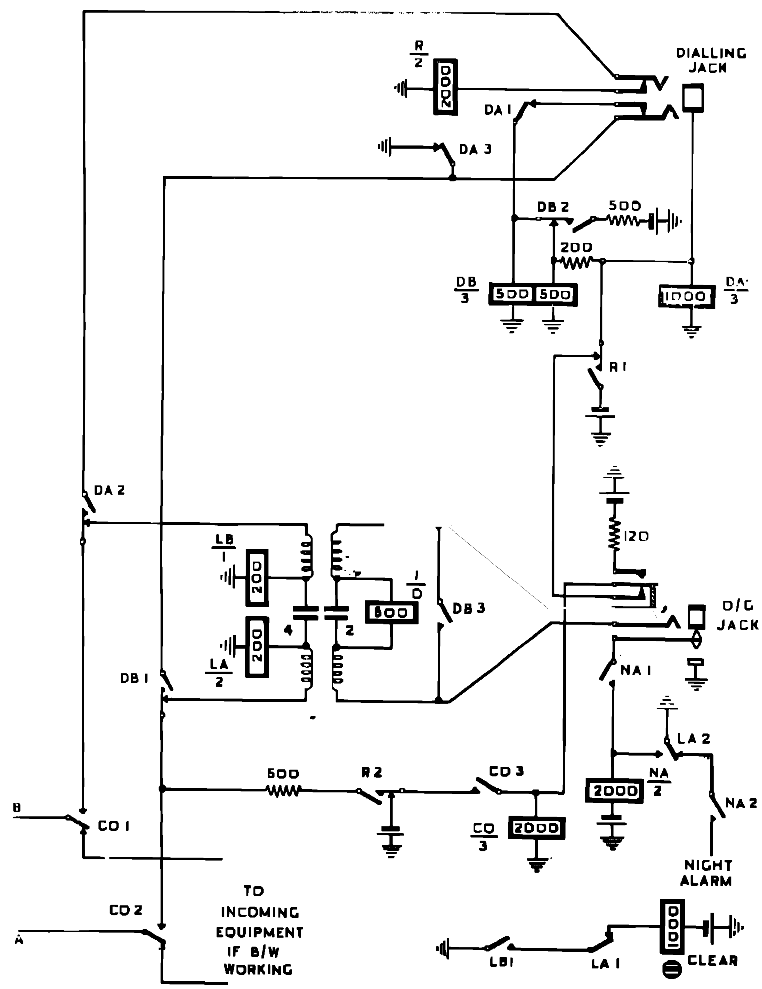


FIG. 455. OUTGOING JUNCTION ARRANGED FOR LOOP DIALLING

The operator receives dialling tone from the automatic exchange selector and inserts the dialling plug into the "dial" jack associated with the junction. Relays *DA* and *DB* operate from the battery supplied via the sleeve of the plug when the dial is moved off-normal. ***DA*2** and ***DB*1** transfer the *B*- and *A*-wires to the dialling circuit, and ***DB*2** retains relay *DB* until the dialling plug is withdrawn on completion of dialling. ***DB*3** short-circuits the tip and ring conductors of the outgoing jack to prevent clicks which would otherwise occur on the release of *DA* after each impulse train. Relay *DA* restores at the end of each train of impulses due to the removal of the battery by the dial off-normal springs. *DA*3 applies an earth for the release of *DB* when the dialling plug is withdrawn; it also completes a holding circuit to the final selector at the automatic exchange should the called party answer before the dialling plug has been withdrawn.

On completion of dialling the operator withdraws the dialling plug and thereby releases relay *DB*. The junction is now restored to the outgoing jack circuit and, when the called subscriber answers, a reversal of the current in the *A*- and *B*-lines causes relay *LA* to operate and *LB* to release. ***LA*1** and *LB*1 control the supervisory indicator. ***LA*2** operates ***NA*** which locks to the auxiliary jack springs at ***NA*1**. ***NA*2** prepares the night alarm circuit in readiness for the release of *LA*2.

At the termination of a conversation, the magneto operator withdraws the calling plug from the outgoing jack. Relay *DA* operates via *R*1 and **CO3** to the battery at *R*2. *DB* also is energized from the same battery when ***DA*1** or ***DA*3** breaks. The automatic equipment is released by the operation of *DA* and *DB* and, when normal conditions prevail from the automatic exchange, relay *R* operates to battery received over the *B*-wire. ***R*1** holds the *DA* relay and ***R*2** releases *CO*. *CO*1 in turn disconnects *R*, which on its release, allows *DA* and *DB* to fall away. The release of relay *CO* is deferred until normal conditions are applied from the automatic exchange in order to prevent false calls on the incoming equipment should the plug be withdrawn before the called party has cleared. Should the operator clear during a busy flash period (i.e. a battery potential on both the *A*- and *B*-wires) relay *R* will operate as usual, but *CO* is held by the busy flash battery on the *A*-wire and so delays the clear-down in order to prevent false calls on the incoming equipment.

The equivalent battery dialling circuit is substantially similar to Fig. 455 except for the insertion of a dialling battery in the ring circuit of the dialling jack.

The C.B.S. No. 1 System. The signalling principles of the C.B.S. No. 1 system have already been considered in Chapter VIII. Briefly, it is a local battery system with automatic d.c. signalling when the subscriber lifts his receiver. The normal condition for calling the exchange is a loop from the subscriber, whilst the clearing condition when the subscriber hangs up is an earth on the *A*-line via the 250 Ω bell at the telephone instrument. The C.B.S.1 system is now obsolescent and no new exchanges of this type will be provided.

Types of Switchboard. The main characteristics

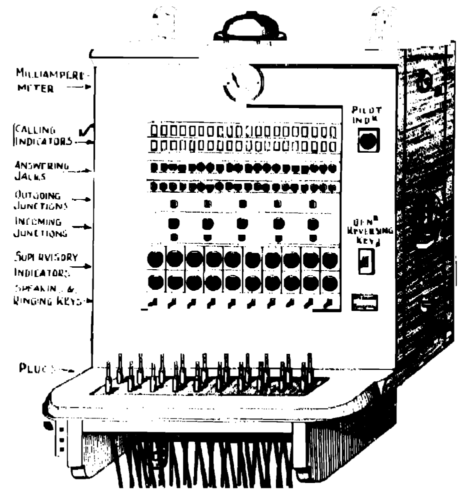


FIG. 456. WALL TYPE C.B.S.1 SWITCHBOARD

$\left(\frac{5 + 20}{45}\right)$

of the various types of C.B.S. No. 1 switchboard are summarized in Table VII. The range extends from a small four-line wall pattern switchboard to a large multiple exchange with a maximum capacity for 800 lines. Fig. 456 gives a general view of a medium size switchboard of the wall type. Provision is made for a maximum of forty subscribers and five junctions with accommodation for ten cord circuits. The speaking and ringing keys are mounted in the jack field since the plug-shelf of this type of switchboard is of open construction and is therefore unsuitable for the mounting of keys. The supervisory indicators are of the eyeball type (Fig. 165) but the subscribers' indicators are of a small and more compact design known as *drum indicators*.

A larger floor pattern type of switchboard is illustrated in Fig. 457. A maximum of 120 subscribers and ten bothway junctions can be accommodated and the section is designed on standard lines. The switchboard has lamp signals both for the subscriber's calling equipment and for the

cord circuit supervisories. The circuits are almost identical with the wall pattern switchboard except that the indicators are replaced by relays, contacts of which close the local lamp circuits. The lamp and its associated relay are combined into one very small unit (Fig. 458), thereby avoiding the provision of a separate relay rack and reducing the amount of wiring required. The panel space in front of the relay is utilized for the circuit designation labels. Whilst the combined lamp and relay offers certain economic advantages, it is doubtful if these are not outweighed by the maintenance difficulties resulting from the somewhat inaccessible position of the unit.

The multiple type switchboard is made up of single position two-panel sections. Each position is normally equipped with sixty calling equipments of the combined lamp and relay type, and the jack field allows of up to 800 multiple (1200 exceptionally) on a four-panel repetition basis. The multiple is of the series (break jack) type and subscribers' meters may be fitted. The exchange can be arranged, if desired, with separate A and B positions and provision can be made for outgoing order-wires, call timing mechanisms and most of the normal C.B. exchange facilities.

Non-multiple Exchange Circuits. Fig. 459 shows the main circuits of a non-multiple C.B.S. No. 1 switchboard of the indicator type. The high resistance indicator (L) is connected to the B-line and operates from the earth at the jack when the line is looped. The C.B.S.1 system was designed for a primary battery power supply at the exchange, and under these circumstances it is important to ensure that the battery drain due to line leakage does not become excessive. A milliammeter is therefore provided in the battery supply to all calling indicators. The milliammeter is fitted on the face of the switchboard and arrangements are made with the operating staff to report if the reading at any time exceeds a specified value.

On receipt of a calling signal the operator inserts the answering plug of a free cord circuit into the line jack and so removes the indicator and the earth from the speaking pair. The cord circuit is of the divided type to give separate supervision from both the calling and called subscribers. The supervisory indicators LA and LC have each two balanced windings of 1000 Ω connected to battery. The indicator is arranged so that it will operate when an earth is connected to the tip of the plug, i.e. to the A-wire of the subscriber's line. The

TABLE VII

SUMMARY OF THE MORE IMPORTANT C.B.S.1 SWITCHBOARDS

Designation	Type	Dimensions			Subscribers		Junctions		Cord Circuits		Distinguishing Features
		Width	Depth	Height	Equipped	Capacity	Equipped	Capacity	Equipped	Capacity	
		ft. in.	ft. in.	ft. in.							
$\frac{2+4}{10}$	Wall	10¾	8½	1 8½	4	8	2	2	2	2	Eyeball type indicators mounted apart from associated jacks. Four double-ended cords to give two-cord circuits.
$\frac{5+20}{45}$	Wall	1 7½	1 1½	2 2	20	40	5	5	5	5	Drum type indicators mounted apart from associated jacks.
$\frac{5+10}{45}$	Floor	1 7¾	2 1½	5 1	10	40	5	5	10	10	Eyeball indicators mounted apart from associated jacks. Subscriber's line capacity can be increased to fifty.
$\frac{5+20}{45}$	Wall	1 7½	1 2⅞	2 1¾	20	60	10	10	7	10	Drum type calling indicators mounted apart from associated jacks. Eyeball supervisory indicators.
$\frac{5+60}{135}$	Floor	1 7¾	2 1½	5 1	60	120	5	15	14	14	Drum type indicators mounted immediately above associated jacks. No multiple facilities but up to three positions may be used with transfer circuits.
$\frac{20+60}{140}$	Floor	1 7¾	2 1½	5 1	60	120	20	20	14	14	Lamp signalling. Otherwise very similar to $\frac{5+60}{135}$
C.B.S.1 Multiple	Floor	1 11	3 5¼	6 5	60	200	30	70	17	17	Lamp signalling. Two-pane one-position sections. Multiple type with capacity fo 800 subscribers. Subscriber and outgoing junction multiples recur every four panels.

second coil of *LA* is introduced primarily to provide an impedance balance of the *A*- and *B*-lines. To obtain the maximum impedance to any speech currents circulating round the loop, the two windings are connected so that their magnetic effects assist when a current circulates round the subscriber's loop. It follows that with this arrangement any currents passing along the *A*- and *B*-wires in the same direction produce equalizing effects in the windings of the supervisory indicator. An earth or low insulation at, say, the subscriber's premises, thus produces similar currents in the *A*- and *B*-wires, but the differentially connected indicator windings prevent possible false operation of the clearing signal due to such a fault.

The ringing and speaking keys are, as usual, combined as one double-throw key, and the speak side has an additional make contact which closes the primary of the operator's telephone circuit only when a speak key is thrown. The magneto hand generator or the equivalent ringing vibrator has one side connected to earth, and the ringing current is fed out over the *A*-wire when the ringing key is thrown. Contact ***LC*1** is made to apply earth via a 2000 Ω resistor to the sleeve of the answering plug when the called subscriber clears. As will be seen later, this is to provide through clearing to the originating exchange on calls routed through the C.B.S.1 switchboard. The circuits of the lamp calling non-multiple switchboard are substantially similar except that the *LA* and *LC* contacts now control the lamp signals.

Multiple Exchange Circuits. Fig. 460 shows the subscriber's line circuit, the cord circuit and various common circuits of a C.B.S.1 multiple type switchboard. The operation of the line relay *L* lights the calling lamp at ***L*1** and the resulting current energizes the low resistance pilot relay *PR*. ***PR*1** operates the eyeball type pilot indicator. The cord circuit is very similar to that of the non-multiple exchange. The *LC* relay is, however, now connected via break contacts of the speaking key so that a clearing signal is not given to an originating exchange whilst the operator is in circuit. The 1000 Ω battery on the sleeve of the cord circuit produces a potential drop across the

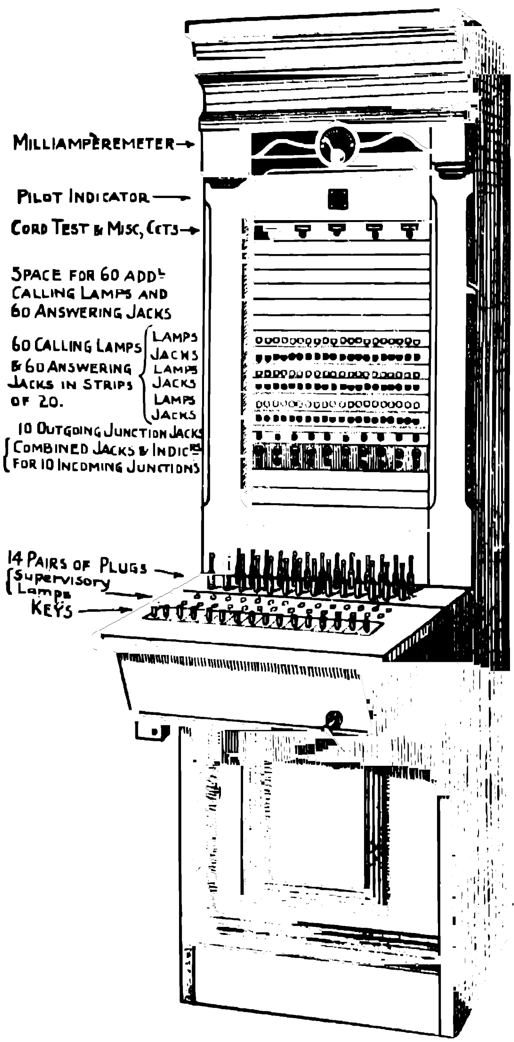


FIG. 457. FLOOR PATTERN C.B.S.1 SWITCHBOARD

$\left(\frac{20 + 60}{140}\right)$

300 Ω resistor in the line circuit to give standard click test conditions on an engaged line.

When subscribers' meters are provided, registration is controlled over the sleeve conductor from an Effective Meter Key in the cord circuit. The depression of this key applies 30 V to the sleeve of the answering plug via a low resistance relay *MR*. The subscriber's meter operates to the increased current in the sleeve circuit and, when the meter is fully operated, a second 40 Ω coil is connected in parallel with the 500 Ω coil. The still greater current in

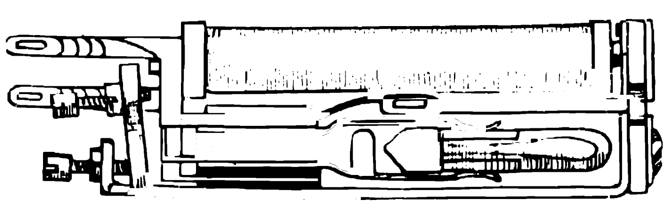


FIG. 458. COMBINED RELAY AND LAMP

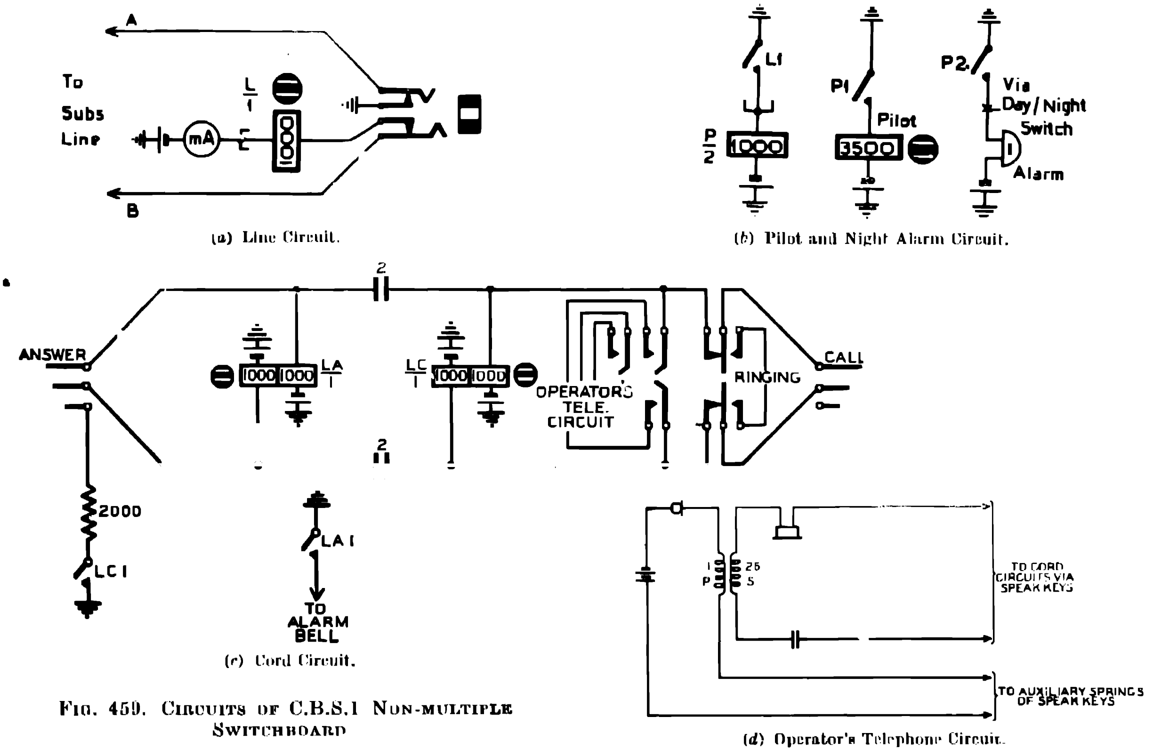
(No. 100A.)

the sleeve circuit now operates relay *MR*. *MR*1 operates a position meter and the local contacts of the latter control a *meter pilot* indicator on the position. The operation of the pilot thus indicates that both the subscriber's and the position meters have operated correctly. The currents in the sleeve and meter circuits under the various conditions prior to and during metering are indicated below. The tabulation also gives the potential on the bush of the jack at each stage.

Stage	Conditions	Current in Sleeve cct. (mA)	Current in meter (mA)	Current in *MR* relay (mA)	Potential of bush (V)
1	Before called subscriber answers (*LC* operated)	21	7·8	—	− 3·9
2	During conversation (*LC* released)	20	7·6	—	− 3·8
3	Meter key depressed but meter not fully operated	160	60	166	− 30
4	Meter key depressed and subscriber's meter fully operated	910	60 + 750	916	− 30

Allowing a reasonable margin for safety, it is apparent from these figures that the *MR* relay must be adjusted so that it does not operate with, say, 200 mA, but is fully operated with a current of, say, 800 mA. Similarly, the subscriber's meter must not operate with a current of, say, 10 mA in its 500 Ω coil, but must operate when the current is increased to about 45 mA. It will be noted that the engaged test potential increases during metering from some 4 V to 30 V.

A second meter and a common "Ineffective Meter Key" per position are also provided. The operator depresses the ineffective meter key each time she deals with a call which cannot, for some reason or other, be completed. The local contacts of the ineffective meter operate the normal or totalling meter and, as before, the meter pilot indicates that metering has been completed. The



(*a*) Line Circuit.

(*b*) Pilot and Night Alarm Circuit.

(*c*) Cord Circuit.

(*d*) Operator's Telephone Circuit.

FIG. 459. CIRCUITS OF C.B.S.1 NON-MULTIPLE SWITCHBOARD

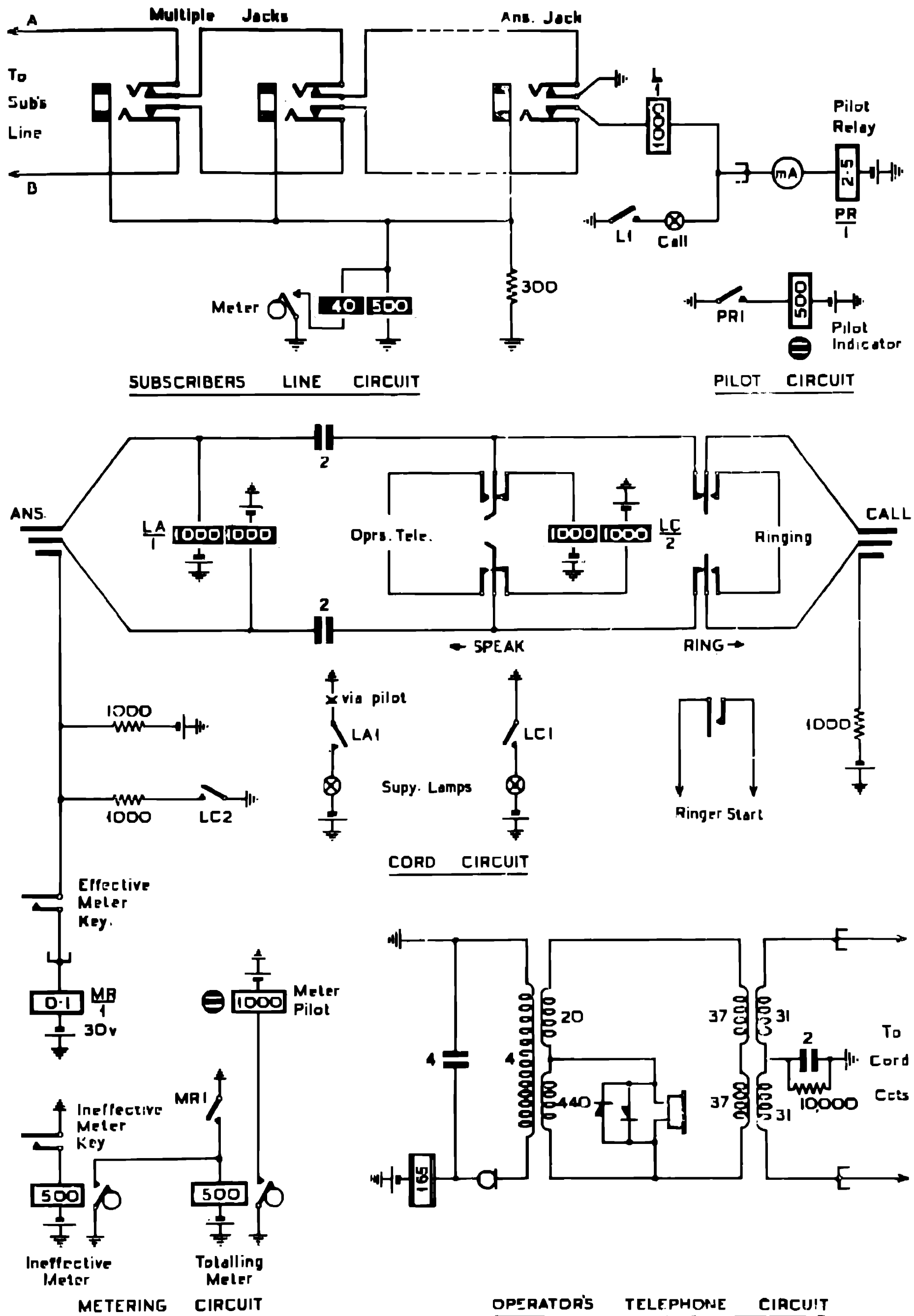


Fig. 460. Circuits of C.B.S.1 Multiple Switchboard

two position meters are required to give statistical data concerning the operator's load. The totalling meter readings give the total number of calls dealt with by the operator during any specified period whilst the ineffective meter readings show the number of such calls which are uncompleted.

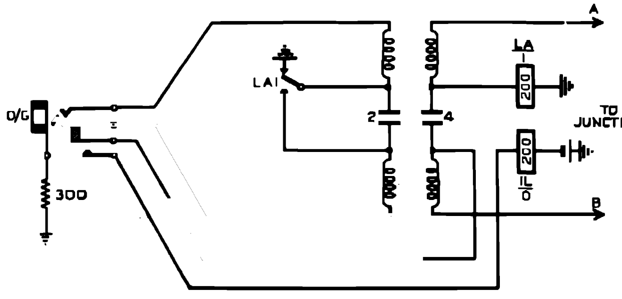


FIG. 461. OUTGOING JUNCTION—C.B.S.1 EXCHANGE

The difference between the two readings gives the number of effective calls.

The operator's telephone circuit is of the type designed to reduce sidetone, and rectifiers across the receiver prevent acoustic shocks. (See Chapter V.) The isolating transformer is introduced to safeguard the rectifiers, and the 2 μF condenser in conjunction with the 10 000 Ω shunt provide the surge required for the "click" engaged test.

Junction Working. Junctions between C.B.S. exchanges and other manual exchanges are usually worked on a C.B. signalling basis. In the outgoing circuit shown in Fig. 461 the calling battery on the B-wire is applied by the auxiliary jack springs when a calling plug is inserted into the jack. When the distant operator answers, battery returned on the A-wire operates relay LA, which at $LA1$ removes the earth from the tip and loops the speaking pair. Contact $LA1$ thus simulates the conditions of a subscriber's switchhook and controls the cord circuit supervisory indicator accordingly.

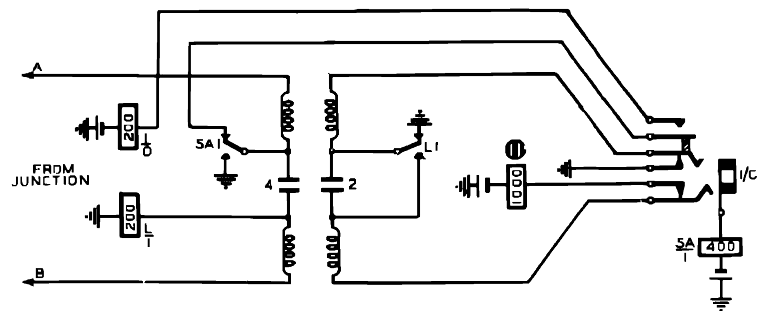


FIG. 462. INCOMING JUNCTION—C.B.S.1 EXCHANGE

The incoming junction (Fig. 462) is arranged so that a battery on the B-wire operates relay L, which, at $L1$ completes the circuit for the calling indicator. When the operator answers, battery is returned on the A-wire by the operation of the auxiliary jack springs, and the calling indicator is disconnected by the break contacts of the jack. As before, contact $L1$ controls the cord circuit supervisory indicator. If an incoming call is extended to another exchange, tbe supervisory indicator (LC, Figs. 459 or 460) associated with the calling cord is operated when the subscriber on the terminal exchange clears. Contact $LC1$ (Fig. 459) applies a 2000 Ω earth to the sleeve of the answering cord which in turn operates relay SA. $SA1$ removes the battery from the A-wire of the incoming junction and thus repeats the clear to the originating exchange operator who, in due course, takes down the connexion thereby releasing L and giving the clear to the C.B.S. exchange. Owing to the small number of junctions usually involved, it is the normal practice to work circuits at a C.B.S. exchange on a bothway basis. Bothway circuits are in principle identical to the outgoing and incoming circuits already considered and there is therefore no need to consider them in detail.

Calls to and from automatic exchanges are handled on circuits very similar to those already considered under the Magneto System. As in the latter system, special incoming circuits from auto subscribers are provided, and metering is effected by the depression of a meter key when the called subscriber answers. (See Fig. 452 for the equivalent magneto circuit.) Similarly the C.B.S. operator dials into the automatic network by means of a special dialling plug which is used in conjunction with a dial jack associated with each junction, the circuit being arranged for battery dialling if the line resistance exceeds the limit for satisfactory loop dialling.

The C.B.S. No. 2 System. The C.B.S. No. 2 system differs from the C.B.S.1 system in the method of clearing. The calling condition on both systems is a d.c. loop from the subscriber's telephone, but the clearing signal in the C.B.S.2 system is a disconnexion for direct current formed by the condensered bell circuit, whilst the C.B.S.1 system provides an earth on the A-line to clear. The C.B.S.2 system is more reliable and provides

the same calling and clearing signals as central battery and automatic systems. It has, therefore, largely replaced the C.B.S.1 system.

464. The 1000 Ω inductive winding of the calling indicator is earthed and is connected to the *A*-line, battery being supplied over the *B*-line via a

TABLE VIII
SUMMARY OF THE MORE COMMON C.B.S.2 SWITCHBOARDS

Designation	Type	Dimensions			Subscribers		Junctions		Cord Circuits		Distinguishing Features
		Width	Depth	Height	Equipped	Capacity	Equipped	Capacity	Equipped	Capacity	
$\frac{5 + 20}{70}$	Floor	ft. in. 1 8¼	ft. in. 2 2¼	ft. in. 4 7	20	60	10	10	7	10	Disc indicators. Designed for installing against wall. Provides through signalling.
$\frac{20 + 60}{160}$	Floor	2 2	2 3¼	4 10¾	60	100	20	60	12	14	Disc indicators. Two-panel switchboard designed for installing against wall. Provides through signalling.
$\frac{20 + 60}{240}$	Floor	2 1	2 10¼	6 4¼	60	180	20	30	14	16	Disc indicators. Two-panel section. Facilities for partial multiple up to limit of 200 jacks per section.

Types of Switchboard. Table VIII gives a summary of the main types of C.B.S.2 switchboard. All are of the floor pattern and the two smaller sizes are designed to stand against a wall to economize in floor space. The largest type is normally equipped for sixty subscribers arranged in two panels, but this number can be increased up to a maximum of 180. The calling signals are of the disc indicator type and are arranged immediately below the associated line jacks. There is accommodation for up to sixteen cord circuits per position. The face equipment and keyshelf lay-out of the large type switchboard are illustrated in Fig. 463. C.B.S.2 switchboards were not originally intended for multiple working, but the panel capacity of the large type board is such that partial multiple facilities (up to 200 jacks per section) and a four-panel outgoing junction multiple (limit eighty circuits) can be provided if necessary. The multiples are of the series type.

Line, Cord, and Operator's Circuit. The subscriber's line circuit, cord circuit, etc., of a typical C.B.S.2 switchboard are illustrated in Fig.

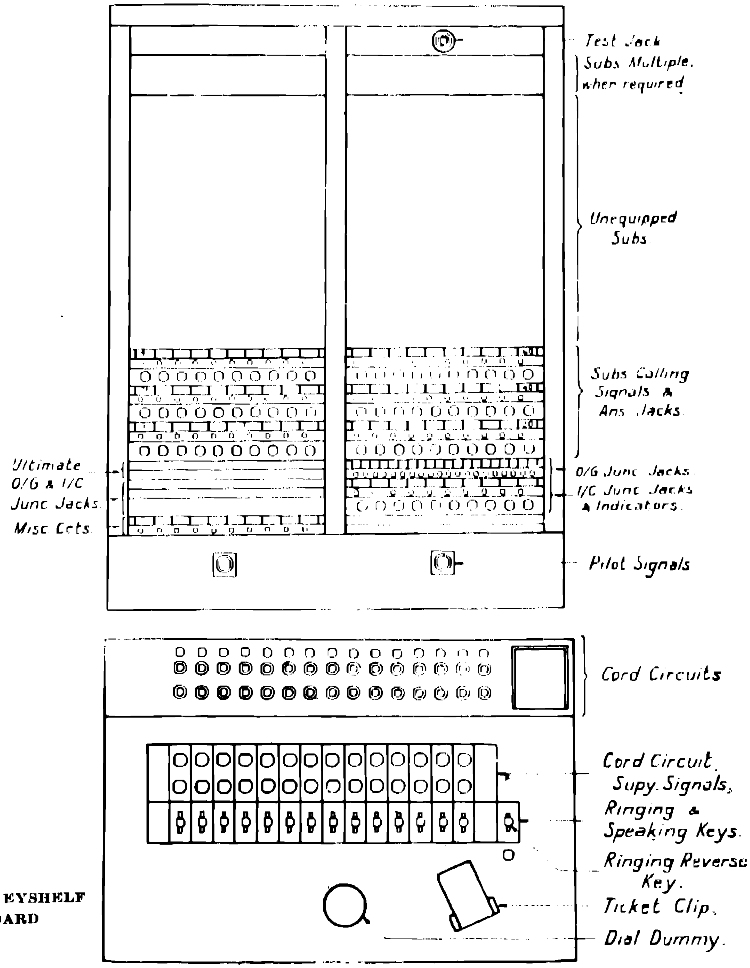


FIG. 463. FACE EQUIPMENT AND KEYSHELF LAY-OUT OF C.B.S.2 SWITCHBOARD $\left(\frac{20 + 60}{240}\right)$

$1000\ \Omega$ non-inductive resistance which, for convenience, is wound on the indicator coil. This arrangement of connecting the calling indicator to the earth side of the circuit is opposite to that employed in the C.B.S. No. 1 and C.B. systems, and whilst it prevents false operation of the indicator to earth faults on the line, it does not of course draw attention to such faults as in the other systems. A milliammeter connected in the battery supply circuit to all calling indicators is, however, provided so that a continual watch can be kept on the total leakage current. The bush of each subscriber's jack is connected to earth via a $1500\ \Omega$ resistor to give distinguishing conditions to the cord circuit when a plug is inserted in a subscriber' line as distinct from an incoming junction jack the bush of which is connected to full earth.

On receipt of the calling signal, the operato inserts the answering plug of a free cord circuit into the subscriber's answering jack and the calling indicator, being disconnected at the jack springs, restores to normal. The cord circuit is of a universal type to give through clearing when used on incoming junction calls, but when used to answer a local subscriber it provides a continuous supervisory battery to the caller. Thus, on local calls, the battery via *IA* is continuously applied to the ring of the answering plug whilst, on incoming

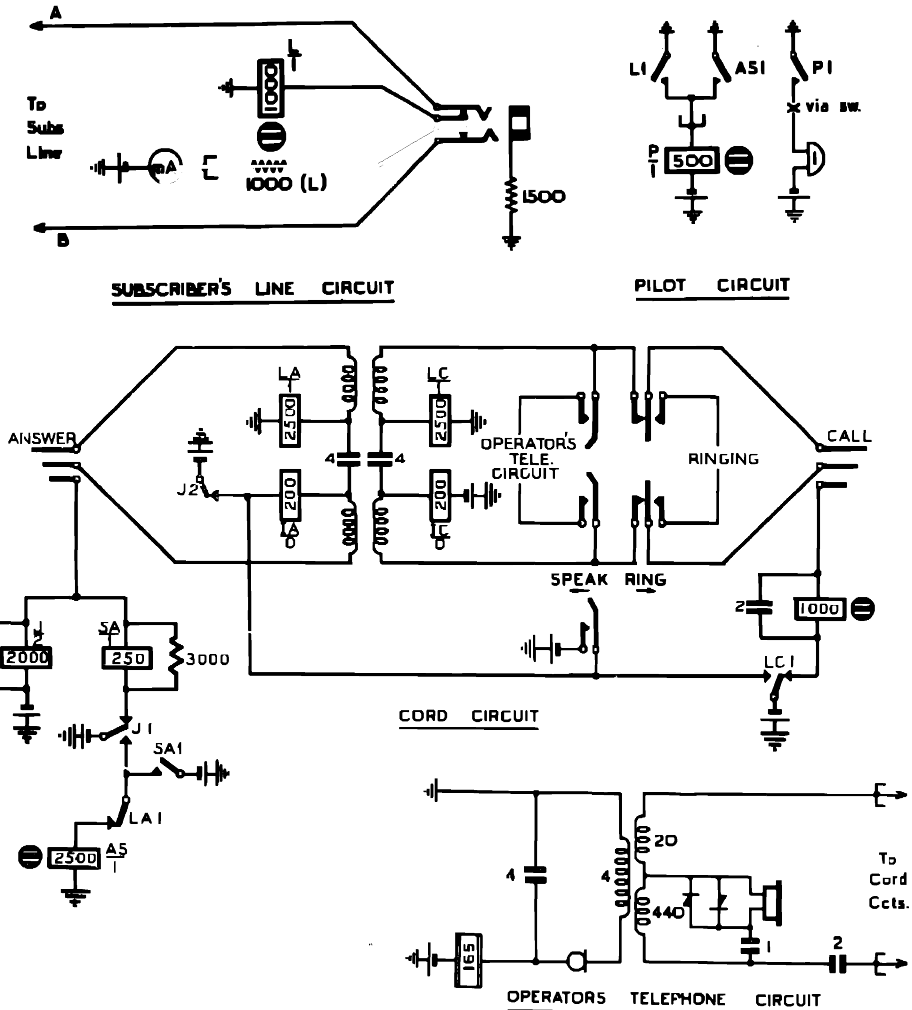


Fig. 464. Circuits of C.B.S.2 Switchboard

junction calls, this battery is connected only when the called subscriber answers or when the operator throws her speaking key. The change-over from one condition to the other is determined by the resistance of the sleeve circuit.

When the cord circuit is used to answer a local subscriber, relay *SA* operates to the 1500 Ω earth in the subscriber's line circuit, but the current is insufficient to operate relay *J*. ***SA*1** completes the circuit of the answering supervisory indicator (*AS*), but almost at the same time this circuit is broken by ***LA*1** due to the operation of *LA* over the subscriber's loop. The calling cord supervisory indicator is operated when the call is established until such time as the called party replies and, at the end of the conversation, separate positive clearing signals are given by the release of *LA* and *LC*. The C.B.S.2 exchange was designed for primary battery operation, and high resistance signalling circuits are a feature of this system.

The high resistance in the supervisory circuit is not divided equally between the indicator *LA* (or *LC*) and retard *IA* (or *IC*) as would be expected, but is concentrated in the supervisory indicators which are connected to the tip or earthed side of the circuit. Thus *LA* and *LC* are made 2500 Ω each and the impedances *IA* and *IC* have a nominal value of 200 Ω only. This arrangement maintains the high resistance conditions for subscriber-to-subscriber connexions and at the same time reduces to a minimum the resistance in series with the ring circuit battery which is used for junction signalling. The use of different impedances connected to the tip and ring conductors introduces a serious unbalance of the *A*- and *B*-wires which would ordinarily produce considerable noise and interference. To minimize this unbalance, a repeating coil is employed and, by the use of 4 μF condensers, the impedance of each line to earth is more or less equalized.

The operator's telephone circuit shown is of the standard design for a secondary cell installation. If primary cells are employed, a separate 3 V battery is used for the operator's transmitter and the circuit is similar to that shown in Fig. 459.

Junction Working. Wherever the line resistance permits, C.B. signalling is used for junctions to and from C.B.S.2 exchanges. It will be remembered that in C.B. signalling, battery is sent out on the *B*-wire to call and battery is returned over the *A*-line when the distant operator or called subscriber answers. In the magneto and C.B.S. No. 1 systems, it is necessary to provide auxiliary apparatus in the junction terminations in order to give the required conditions, but the C.B.S. No. 2 system (being a derivative of the C.B. system) automatically sends out battery on the *B*-wire from the cord circuit whenever a plug is inserted into an outgoing jack. Also by reversing the tip and ring wires of all incoming junctions, battery is returned over the *A*-wire from the cord circuit when the operator answers. Ordinarily, therefore, no equipment whatsoever (with the exception of the calling indicator on incoming circuits) is required on outgoing or incoming junctions at a C.B.S. No. 2 exchange.

The arrangements are as shown in Fig. 465

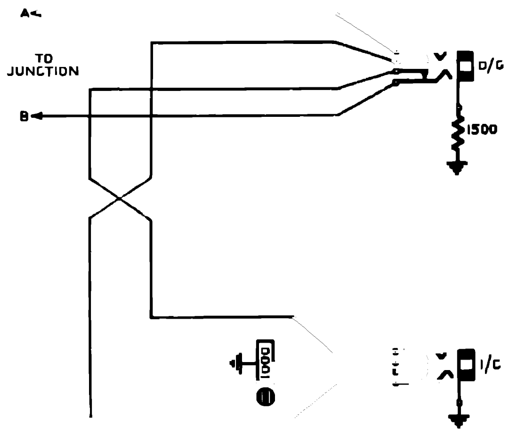


FIG. 465. BOTHWAY C.B. SIGNALLING JUNCTION

which illustrates a circuit arranged for both incoming and outgoing traffic, i.e. a bothway circuit. Unidirectional incoming or outgoing junctions are, if required, connected as the lower and upper jacks of Fig. 465 respectively, but such circuits are rarely used owing to the small junction groups usually required at C.B.S. exchanges. The *A*- and *B*-lines are reversed to the incoming jack, and a calling battery on the *B*-wire operates the 1000 Ω earthed indicator connected to the tip of the circuit. The junction is also connected so that the insertion of a plug in the outgoing jack disconnects the incoming side of the circuit at the jack springs. It should be noted that the bush of the incoming jack is connected to full earth, whereas the outgoing jack has a 1500 Ω resistance similar to an ordinary subscriber's line.

When the operator answers an incoming call, relay *J* in the cord circuit (Fig. 464) operates to the full earth on the bush and at ***J*2** removes the battery from the answering side of the cord circuit. *SA* also operates over the sleeve circuit but is immediately disconnected by ***J*1** which also provides a battery to the supervisory indicator in place of that normally connected at ***SA*1**. The 2 μF condenser in the sleeve circuit is introduced to avoid

electric shock due to the high inductance of the sleeve relays, and also prevents the false operation of *J* to surge currents.

When the operator enters the circuit, auxiliary Speak key contacts apply battery to *IA* and thence over the *A*-wire of the junction to give a supervisory signal at the originating exchange. This battery is similarly applied by **LC1** when the called party replies. At the end of the call, *LC* releases as the called subscriber replaces his receiver and battery at **LC1** only when the called subscriber answers, and the circuit is so arranged that *C* does not operate due to any momentary flick of *LC* when the calling plug is being inserted into the subscriber's jack. At this stage the speaking key is normally thrown and the circuit of *C* is broken at the additional speaking key contacts. After the operation of *LC*, the *C*-relay is held by **C2** should the Speak key be thrown at any time during the progress of a call.

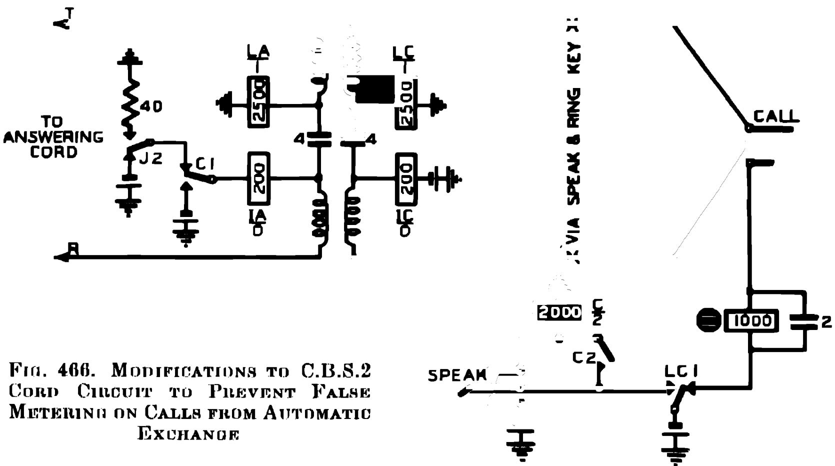


Fig. 466. Modifications to C.B.S.2 Cord Circuit to Prevent False Metering on Calls from Automatic Exchange

At the termination of the conversation, the *LC* and *C* relays release and the battery on the *A*-wire is replaced by the 40 Ω earth until such time as the answering plug is withdrawn. The 40 Ω earth on the *A*-wire now prevents the reseizure of the junction at the automatic exchange until the connexion is severed at the C.B.S. exchange.

LC1 removes the battery on the *A*-wire to give a through clearing condition.

Calls from Automatic Areas. If the C.B.S.2 exchange is within the metering range of an automatic exchange, subscribers of the latter may be permitted to obtain access to the C.B.S. exchange by dialling a predetermined code. Often the junctions are also used by the automanual operators and by other manual exchanges where it is economical to route such calls via the automatic exchange. The bothway or incoming junction circuit already considered (Fig. 465) is suitable for calls from automatic areas, but the normal C.B.S.2 cord circuit provides for the return of supervisory conditions when the incoming operator answers. Modifications are therefore necessary to prevent false registration on calls from automatic subscribers. All cord circuits on the position or positions dealing with dialled out calls are modified as shown in Fig. 466. Relay *J* (Fig. 464) operates as before when the answering plug is inserted into an incoming junction jack, and hence battery is not returned on the *A*-wire (ring conductor) until contact **C1** operates. The 40 Ω earth returned on the operation of **J2** disconnects the ring tone which is applied by the outgoing relay set at the automatic exchange. Relay *C* operates from the

It is apparent that on any position equipped with the modified cord circuit, key supervision is eliminated and hence there is no supervision if the operator on this position answers any call received on an incoming junction from another manual exchange. It is not practicable to provide both automatic metering and key supervision, but if the traffic from auto exchanges is small as compared with the total incoming junction traffic, it is sometimes preferable to retain the standard cord circuit (with key supervision) and to install special equipment on the junctions incoming from automatic areas.

Bothway Circuit from Auto. A bothway circuit for dealing with calls incoming from an automatic exchange is given in Fig. 467. It is similar to the ordinary bothway circuit, but with the addition of a meter key and "subscriber's answer" lamp, together with the associated relays *M*, *S*, and *LA*. The insertion of a plug into the incoming jack disconnects the calling indicator from the *B*-line. Relay *S* operates on its 12 000 Ω winding to the battery on the sleeve of the plug via relays *J* and *SA* in the cord circuit. ***S*1** connects earth to the bush of the jack via the 27 Ω winding of *S* and the increased current allows relay *J* to operate. The *S*-relay must be low resistance in order to operate *J*, but the 12 000 Ω pre-operating winding ensures that *S* is fully operated before *J* disconnects relay *SA*. The operation of the speaking key when the

operator answers feeds battery via the ring of the plug to operate relay *LA*. ***LA*1** connects its 100 Ω earthed winding to the *A*-line of the junction to disconnect ringing tone at the automatic exchange. ***LA*2** lights the "subscriber's answer" lamp. The operator completes the connexion and restores the speaking key, thus releasing *LA* and leaving it under the control of the called subscriber's switch-hook. When the called subscriber answers, *LA* operates to battery returned over the ring of the answering plug and ***LA*2** relights the subscriber answer lamp. The operator then depresses the plunger type meter key and operates relay *M* which holds via ***M*3** to the ***S*1** earth. ***M*2** short-circuits the 2 μF condenser, thereby allowing the supervisory battery to be returned over the *A*-wire to effect metering at the automatic exchange. ***M*2** also releases *LA* which at *LA*2 extinguishes the

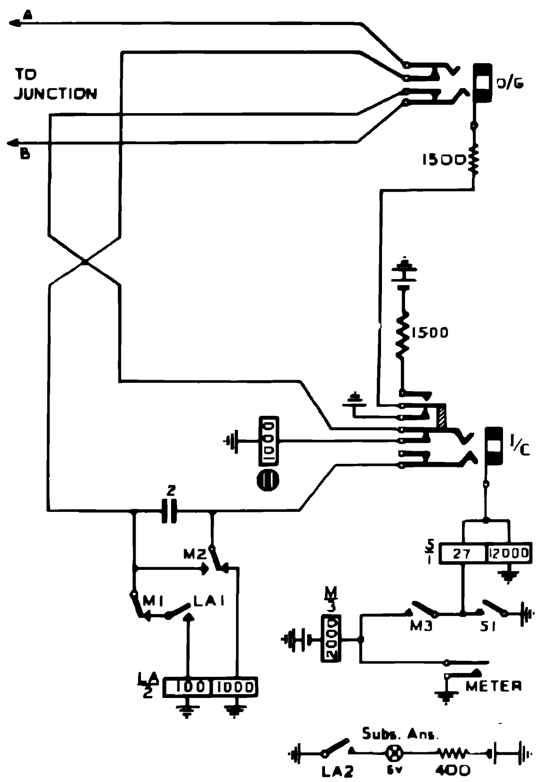


Fig. 467. Bothway Circuit to Automatic Exchange

subscriber answer lamp. Release of the call is similar to the ordinary incoming circuit.

Although the standard cord circuit is apparently suitable for use on a position where incoming junctions to Fig. 467 are terminated, the cord circuits are in practice a modification of Fig. 466. Contact *C*2 is permanently short-circuited and hence the *C* relay is energized whenever either the speak key is thrown or when contact ***LC*1** is operated. Thus standard key supervision is afforded but the arrangement of the *C*1 and *J*2 contacts

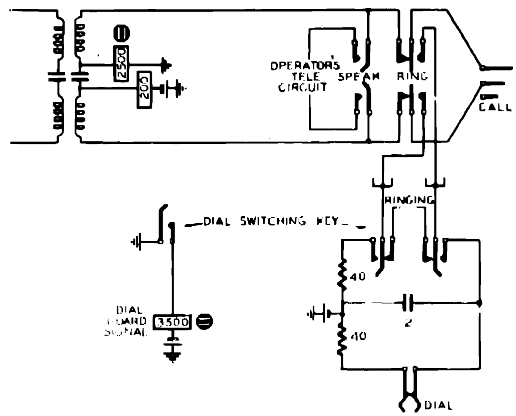


Fig. 468. Dial Circuit

allows the return of the 40 Ω earth over the *A*-wire, which on calls from an automatic area is used to trip the ringing tone. As in the previous circuit, the 40 Ω earth also prevents re-seizure of an outgoing circuit at the automatic exchange until the connexion is taken down at the C.B.S. exchange at the end of a conversation.

Dialling to Automatic Areas. When the traffic conditions are suitable, it is usual for C.B.S. operators to dial numbers required on adjacent automatic exchanges. In the magneto and C.B.S.1 systems, special dialling jacks associated with each junction are provided and connexion between the operator's dial and the line is made by means of a dialling plug. In the C.B.S.2 system, however, there is no bridging apparatus on outgoing junctions and it is possible to dial through the calling plug from the cord circuit which is to be used for the conversation. A special dial key is provided per position which is connected, so that by throwing the key, an operator can cut off the ringing supply to all cord circuit ringing keys on the position and substitute the dial impulse springs. The arrangement is shown in Fig. 468. The ringing key is of the non-locking type so that when the operator wishes to dial, she first throws the dial switching key and then holds the ring key in the operated position until the dial returns to normal after the last train of impulses. There is a danger that the operator may forget to restore the dial key after setting up a call, with the resultant disconnexion

of the ringing current from all cord circuits. To guard against this contingency, an indicator operated by auxiliary springs of the dial switching key draws attention to the fact that the dial key has been left in the thrown position.

Irrespective of the junction resistance, battery dialling is universally adopted from C.B.S.2 exchanges owing to the high resistance of the cord circuit indicators and to the variable voltage of the battery when primary cells are used. The conditions are as shown in Fig. 469. On the release of the ringing and dial keys, a 2500 Ω earth is applied to the *A*-wire of the junction and a 200 Ω battery is fed to the *B*-wire from the cord circuit. If loop dialling were used, the impulsing relay (*A*-relay) of the automatic exchange selector would have to be held until the called subscriber answered by the difference in potential between the automatic exchange and C.B.S. exchange batteries via the junction resistance plus that of the retard coil. Although the C.B.S. exchange battery has a normal p.d. of 22 V, the voltage may in fact vary from a maximum of about 30 V to a minimum of some 16 V when primary cells are used. Assuming that the p.d. of the automatic exchange battery is 50 V and the C.B.S. exchange battery has its peak voltage of 30, there remains only 20 effective volts to maintain a satisfactory holding current over the resistance of the *B*-wire of the junction. In this connexion, allowance must also be made for possible differences in earth potential between the two exchanges, and hence it is impossible to obtain the necessary holding conditions in a vast majority of the cases. When the called subscriber on the automatic exchange answers, the potential is reversed at the automatic end and the *A*-relay of the selector must be held by the current on the *A*-wire due to the battery supplied from the automatic exchange plus the effect of the current on the *B*-wire from the battery at the C.B.S. exchange. The former current is extremely low owing to the presence of the 2500 Ω supervisory indicator and is therefore of very little value. The current on the *B*-wire similarly cannot be relied upon owing to the large fluctuations in the battery voltage of the C.B.S. exchange. Hence it is the standard practice to employ battery dialling from all C.B.S.2 exchanges and to provide the necessary incoming relay sets at the automatic exchange to receive the battery impulses.

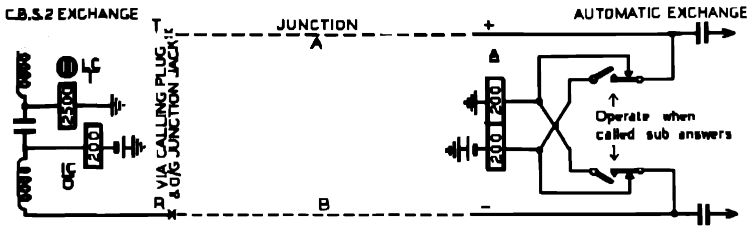


Fig. 469. Conditions which Prevent Loop Dialling from a C.B.S.2 Exchange

EXERCISES XV

1. Explain why magneto exchanges and the instruments connected to them are now invariably "condensered."

2. Give a diagram of a junction at a magneto exchange incoming from a nearby automatic exchange. Explain how false metering is prevented and how at the end of a call the junction is engaged at the automatic exchange until the incoming magneto operator breaks down the connexion.

3. Show how metering is effected at a C.B.S.1 multiple exchange.

4. Describe how an outgoing C.B. signalling junction is provided at a C.B.S.1 exchange.

5. Draw the subscriber's line and cord circuits of a C.B.S.2 switchboard. Why is the impedance element in the "tip" circuit of 2500 Ω resistance whilst that in the "ring" circuit is only 200 Ω?

6. How is through clearing provided on a C.B.S.2 switchboard?

7. Give the circuit elements of a call from an automatic exchange to a nearby C.B.S.2 exchange.

8. Why can loop dialling not be employed from a C.B.S.2 exchange? Illustrate your answer with suitable diagrams.

9. Explain how you would convert a C.B.S.2 exchange to full central battery (C.B.) working at the minimum cost.

CHAPTER XVI

THE CENTRAL BATTERY SYSTEM: LOCAL CALLS AND EXCHANGE DESIGN

Of the various manual switching systems, the Central Battery System is generally recognized as the most efficient arrangement for the majority of working conditions and has, in fact, superseded all other systems of manual switching. The use of a central battery for signalling and for transmission has already been discussed at some length in Chapters V and VIII, and there is therefore no necessity to reiterate in this chapter the fundamental principles involved and the advantages of the system as a whole:

Central battery exchanges are of three main types:

(*a*) Exchanges with a 40 V common battery and with condenser-impedance type transmission bridges.

(*b*) Exchanges with a 22 or 24 V battery and with repeating coil (transformer) transmission bridges.

(*c*) Exchanges with a 22 or 24 V battery in conjunction with condenser-impedance transmission bridges.

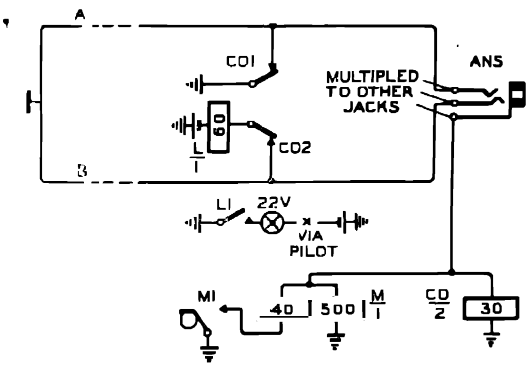


Fig. 470. Subscriber's Line Circuit (22 V)

There is little to choose on the grounds of transmission and signalling efficiency between the 40 V system and the 24 V repeating coil system, although the higher voltage has somewhat better limits of junction and subscriber's line resistance. The 24 V condenser-impedance system has not been extensively used owing to the difficulty of providing transmission bridge elements of the required impedance but with a sufficiently low ohmic resistance.

Subscriber's Line Circuit. A schematic arrangement of the standard C.B. subscriber's line circuit is given in Fig. 470. Three-point branching jacks are utilized and a parallel multiple is employed. When the subscriber lifts his receiver, the *A*- and *B*-lines are looped and relay *L* is operated from the earth at contact *CO*1. The *L*-relay has one contact (**L1**) which lights the calling lamp. On receipt of a calling signal the operator inserts an answering plug into the local jack associated with the calling lamp, and a battery from the cord circuit operates

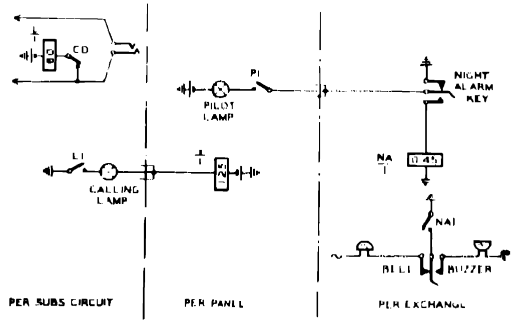


Fig. 471. Pilot and Night Alarm Circuits

CO over the sleeve connexion of the plug. Contacts **CO1** and **CO2** disconnect the earth and the *L*-relay from the *A*- and *B*-lines respectively, thereby removing all bridging apparatus from the speaking pair. The *A*- and *B*-lines are now extended to the cord circuit via the tip and ring conductors of the answering cord. The subscriber's meter does not operate at this stage owing to insufficient current in its 500 Ω winding.

Pilot and Night Alarm Circuit. During periods of light traffic, it is not economical to staff all positions in an exchange. In order to draw attention to a calling signal during periods when the switchboard is only partially staffed, it is usual to provide a pilot and night alarm circuit as in Fig. 471. The battery supply to all calling lamps in one switchboard panel is fed through a common 1·25 Ω pilot relay *P*. The operation of any subscriber's line relay completes a circuit for the relevant calling lamp through the *P* relay which operates. **P1** completes a circuit for a white pilot lamp located in a prominent position below the jack panel to which it refers.

Whilst the pilot lamp gives a visual indication of the panel location of a calling line, an audible

alarm can be added at will by throwing the night alarm key. This key, which is usually provided per exchange or per suite of positions, connects a night alarm relay (*NA*) in the earth supply to the pilot lamps of all panels. Thus, the operation of a line relay on any one position lights the subscriber's calling lamp and the panel pilot lamp, and energizes the night alarm relay for the suite. Relay *NA* has one contact ***NA*1** which in turn controls a bell or buzzer, depending on the position of the change-over key. The bell and buzzer are of the magneto type operated by ringing current to avoid possible failures due to blown fuses or to faulty trembler bell contacts.

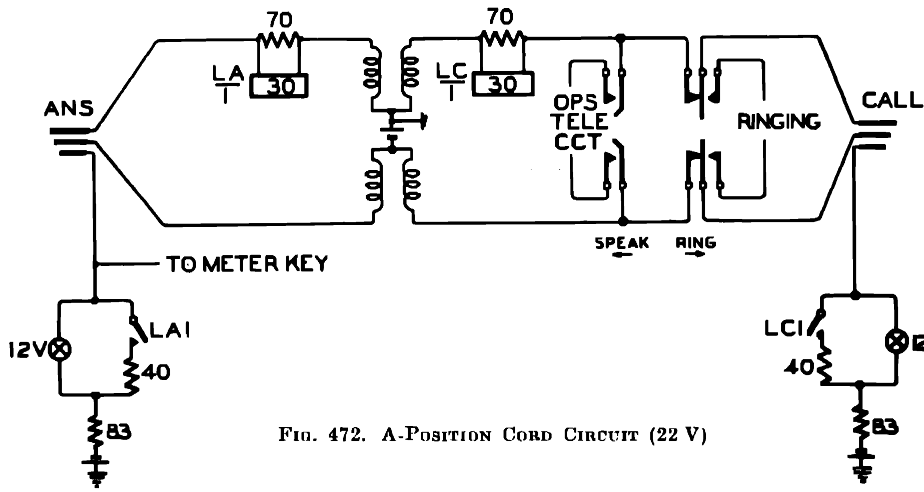


FIG. 472. A-POSITION CORD CIRCUIT (22 V)

A-Position Cord Circuit (22 V). The cord circuit as used on subscriber's or *A*-positions is given in Fig. 472. When the operator inserts an answering plug into the jack of a calling line, battery is fed over the sleeve circuit of the plug via the 83 Ω resistor and the 12 V lamp in series. As stated previously, the resultant current operates relay *CO* in the line circuit. Relay *LA* in the tip conductor of the cord circuit operates from the battery and earth of the repeating coil over the circuit completed by the subscriber's loop. *LA* is in the speaking circuit and, to minimize its impedance to speech and its unbalancing effect on the lines, it is shunted by a 70 Ω non-inductive resistance. Contact ***LA*1** applies a shunt to the answering cord supervisory lamp and so prevents the latter from glowing. If the calling subscriber wishes at any subsequent stage of the call to obtain the attention of the operator, he flashes his switch-hook and thus alternately operates and releases relay *LA*. *LA*1 in turn allows the answering supervisory lamp to flash during each operation of the switch-hook.

After plugging into a calling line, the operator throws the speaking key and requests the number required. The operator now picks up the calling cord of the pair and after testing, inserts it into the nearest multiple jack of the required line. As with the answering cord, the insertion of the calling plug operates relay *CO* of the called line over the sleeve circuit and thereby removes the line relay and earth from the speaking pair. The called subscriber is rung by the operation of the ringing key which sends out to line 17 c/s current for the ringing of the bell. Until the called subscriber answers, the calling cord supervisory lamp glows from the current flowing in the sleeve circuit (from earth at the *CO* relay). When the called subscriber answers, the *A*- and *B*-lines are looped and relay ***LC*** operates to the normal line current. As on the answering side of the cord circuit, ***LC*1** shunts the calling cord supervisory lamp during the whole of the time that the called subscriber's receiver is off the rest.

At the termination of the conversation, both subscribers hang up and relays *LA* and *LC* are released. *LA*1 and *LC*1 allow the answering and calling cord supervisory lamps to glow and the operator, after metering the call against the originating subscriber, takes down the connexion. If only one supervisory lamp glows, it is the usual practice for the operator to enter the circuit to verify that the conversation is finished before she takes down the connexion.

A-Position Cord Circuit. (40 V). Fig. 473 shows the equivalent *A*-position cord circuit for use in 40 V exchanges. The arrangement is very similar to the 22 V circuit with the exception of the transmission bridge which is of the condenser-impedance type. The impedances connected to the tip circuit

(*LA* and *LC*) serve also as supervisory relays. In order to provide a balanced transmission system, impedance coils *IA* and *IC* are usually of relay construction (but without contacts) and are carefully matched for impedance with their associated supervisory relays.

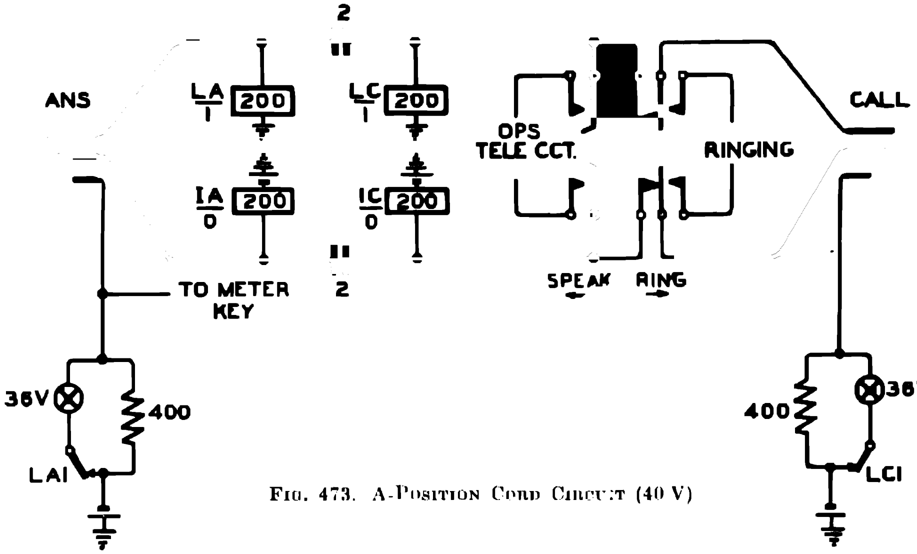


FIG. 473. A-POSITION CORD CIRCUIT (40 V)

As before, contacts *LA*1 and *LC*1 control the answering and calling cord supervisory lamps respectively. In this circuit, however, the operation of either supervisory relay *disconnects* the lamp instead of shunting it as in the 22 V case. The disconnexion method is, generally speaking, better than the shunting arrangement, since failure of the lamp does not break the sleeve circuit. Moreover, the shunting arrangement sometimes introduces difficulties when lamps of different electrical characteristics are used (e.g. metal filament lamps). It is probable that the arrangement of the 22 V circuit was originally adopted to give a lighter spring load (a make instead of a break contact) on the supervisory relay which is of low resistance and receives only a portion of the total line current.

Operator's Telephone Circuit. The operator's telephone circuit (Fig. 474) is of the anti-sidetone type already discussed in Chapter V. The operator's transmitter current is obtained from the common 22 V battery, the current being regulated to the correct value by the insertion of a 165 Ω retard coil in the primary circuit. This retard coil, together with the 4 μF condenser, also prevents the a.c. component of the transmitter current from traversing the main battery, a low impedance path being provided for such currents via the condenser, the 4 Ω primary winding of the induction coil, and the transmitter. In addition to the anti-sidetone arrangements of the secondary circuit, a pair of rectifiers is added across the receiver to prevent acoustic shocks (see Chapter V). The 1 μF condenser in series with the receiver is included as a precautionary measure to prevent any d.c. potentials from being applied to the rectifiers. Similarly

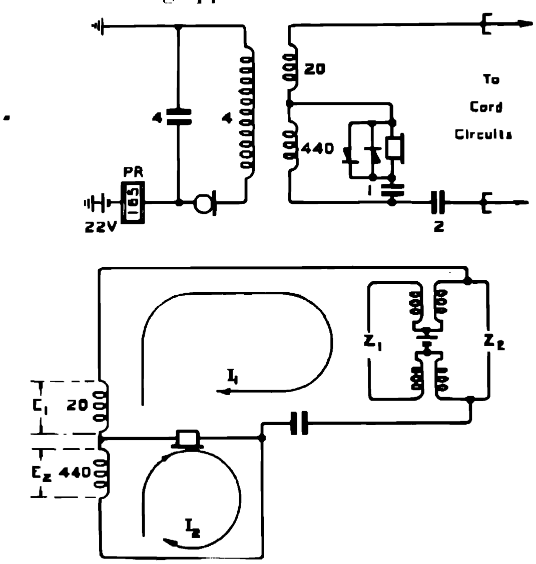


FIG. 474. OPERATOR'S TELEPHONE CIRCUIT (22 V)

the primary function of the 2 μF condenser in series with the ring connexion is to prevent the flow of direct current in the secondary circuit from the battery supply of the cord circuit. The

2 μF condenser also performs an important function in connexion with the testing of a subscriber's line for the engaged condition.

Engaged Test Conditions. The circuit elements involved when an operator tests a subscriber's line for the engaged condition are illustrated in Fig. potential drop in the *CO* relay. The theore circuit conditions are shown in Fig. 476. Poin represents the bush of an engaged line and, fro simple application of Ohm's Law, the potential this point is about 3·5 V negative as compar with the full earth potential of a free line. Th

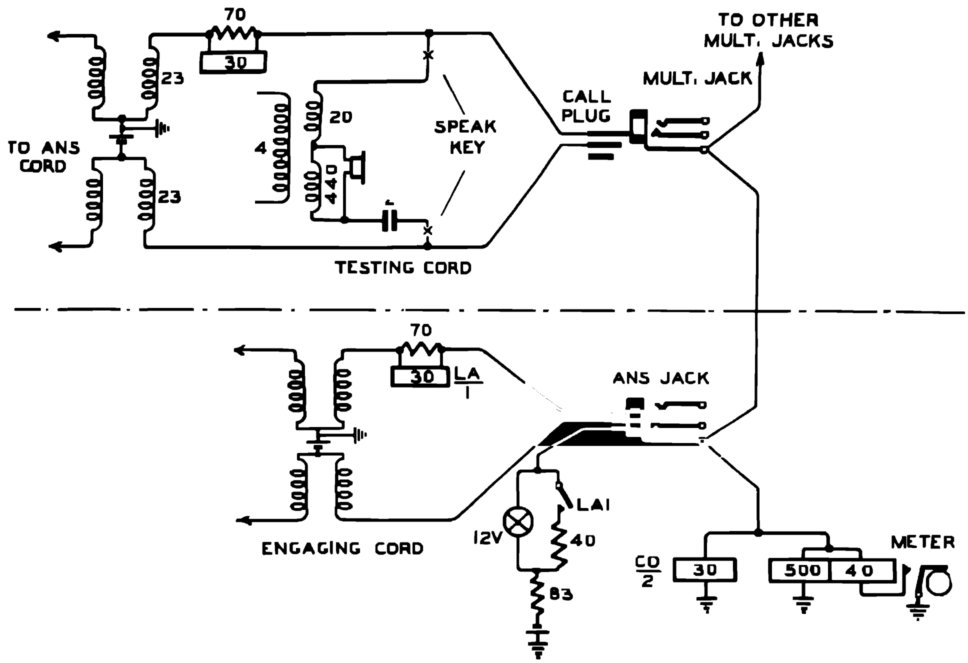


FIG. 475. CIRCUIT CONDITIONS DURING THE TESTING OF AN ENGAGED LINE

475. Ordinarily the bushes of all multiple jacks of a subscriber's line are connected to earth at the *CO* relay of the line circuit. If any line is engaged,

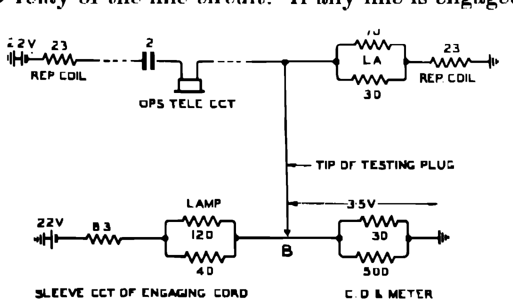


FIG. 476. SIMPLIFIED CIRCUIT OF ENGAGED TEST CONDITIONS

battery is supplied from the sleeve circuit of the engaging cord and the resultant sleeve circuit current produces a potential drop in the *CO* relay. Hence the bushes of all multiple jacks have a negative potential from earth corresponding to the potential difference between the tip and ring conductors of any free plug is normally the same as the p.d. of the exchange battery (this must, of course, be so since in the absence of any current there can be no potential drop in the 23 Ω windings of the repeating coil or in the 30 Ω supervisory relay). When therefore the operator throws a speaking key to associate her telephone with a cord circuit, a momentary current flows in the secondary circuit until such time as the 2 μF condenser in the operator's telephone circuit is charged to the 22 V potential difference of the tip and ring conductors. If now an operator places the tip of such a free plug into contact with a multiple jack of a disengaged line, both the tip of the plug and the bush of the jack are at earth potential. Hence no current flows in the tip circuit and there is no change in the potential difference across the operator's telephone circuit. If, however, the tested line is engaged, the 3·5 V negative potential on the bush causes a current to flow from earth at the repeating coil via the 23 Ω winding and the supervisory relay in series

and ultimately to battery via the sleeve circuit of the engaging cord. The current can be calculated and is, in fact, in the order of 66 mA in the tip circuit of the testing cord. Under these conditions the potential of the bush of the multiple jacks is slightly modified to about 2·9 V negative instead of the 3·5 V existing before the application of the testing plug.

The potential difference across the tip and ring of the cord circuit, and hence across the operator's telephone circuit. is now $22 - 2{\cdot}9 = 19{\cdot}1$ V. The condenser in the latter thus discharges until its potential difference falls to 19·1 V and the momentary discharge current traverses the secondary windings of the induction coil and the operator's receiver, thereby producing a loud click in the latter. When the tip of the plug is withdrawn from the bush of the jack, the condenser in the operator's circuit rapidly regains its original p.d. so that a number of tests can be made in quick succession.

Metering Circuit. In all C.B. exchanges (except very small switchboards of a simplified type) subscribers' meters are provided for the recording of local and junction-fee calls. On the completion of a call and before she removes the plugs from the jacks, the operator depresses a plunger type key associated with the answering cord. One meter key per cord circuit is provided and, on each depression of the key, the originating subscriber's meter makes one step to debit one unit fee against his number. Facilities are also provided for checking the total number of both effective and ineffective calls handled by each operator. For this purpose, two traffic meters are provided per operator's position, and are located in a suitable cabinet in the switchroom. One meter records the ineffective calls and is operated by a special *ineffective meter key* common to the position and which is depressed by the operator each time she handles a call which cannot be completed for some cause or other. The other meter, a totalling meter, records the complete number of calls (both ineffective and effective) dealt with by the operator. It is stepped either by one of the *effective meter keys* associated with the cord circuits or by the position ineffective meter key. The number of effective calls can of course be found by subtracting the readings of the ineffective and totalling meters.

A 22 V exchange meter circuit is given in Fig. 477, the 40 V equivalent circuit being similar except for slight variations in the resistance values. On the depression of the effective meter key, a 30 V potential is applied to the sleeve of the answering plug via the 0·27 Ω totalling meter. In a 22 V exchange, the 30 V is made up by a special four-cell meter battery which is placed in series with the normal exchange voltage. In a 40 V exchange no separate battery is provided, the regular 40 V supply being used for metering purposes. The increased voltage (in the 22 V exchange) together with the shunting of the sleeve resistances (83 Ω, 40 Ω and lamp) increases the current in the subscriber's *CO* relay and meter to such an extent that the latter operates on its 500 Ω winding. The

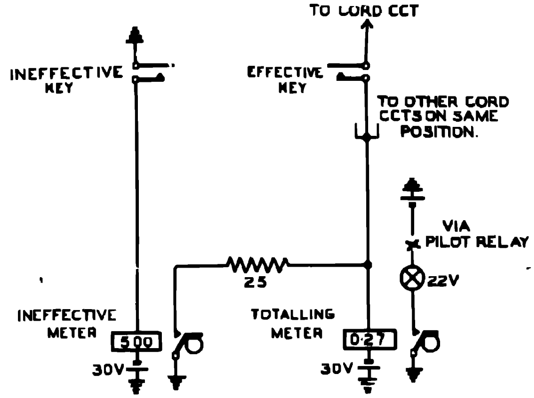


FIG. 477. METERING CIRCUIT

current in the meter is in fact increased from about 9 mA to 60 mA on the depression of the meter key. The current in the 0·27 Ω position meter, although it is at this stage in the order of 1 A, does not operate the position meter. On the operation of the subscriber's meter however, local contacts close the circuit of a 40 Ω winding which is applied in parallel with the 500 Ω winding. This further decrease in the total resistance of the sleeve circuit causes the current to increase sufficiently (to approximately 1·8 A) to operate the position meter, the subscriber's meter holding due to the effects of the two windings in parallel.

The totalling meter is provided with a local make contact which, on the operation of the meter, completes a circuit for a *meter lamp* located in the lamp rail of the position. The momentary glowing of the meter lamp thus indicates to the operator that both the subscriber's meter and the position totalling meter have operated satisfactorily.

The position ineffective meter is operated over a local circuit by the depression of the ineffective meter key. The local contacts of the meter are arranged to step the totalling meter once for each operation of the ineffective meter. The 25 Ω resistance shown in this circuit is provided to simulate the ordinary operating conditions of the totalling meter, and it should perhaps be mentioned that this resistance is in practice made up of a number of resistors to guard against the risk of

fire should the heavy current be maintained due to misoperation or fault conditions.

Long Lines. In some cases it is not possible to provide economically an external line which is of sufficiently low resistance to obtain satisfactory

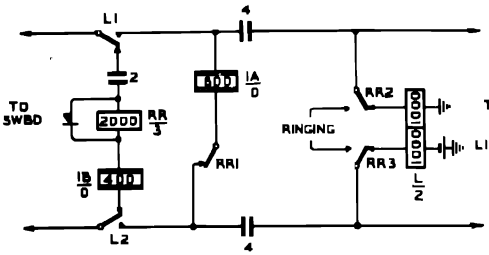


FIG. 478. AUXILIARY EQUIPMENT FOR LONG SUBSCRIBER'S LINES

C.B. transmission or signalling. In these circumstances, local battery instruments are fitted and the auxiliary equipment shown in Fig. 478 is introduced between the line and exchange equipment. Relay *L* is a sensitive relay which operates when the

When the subscriber answers, *L* operates at the first cessation of ringing and ***L*1** and ***L*2** disconnect relay *RR*. The release of *RR*1 applies the supervisory loop to the cord circuit.

Call Office Circuits. The detailed circuit arrangements of the prepayment type of call office used with the C.B. system have already been considered in Chapter IX. Fig. 479 shows the special line and cord circuits provided at the C.B. exchange for the handling of coin-box calls. The main signalling elements of a call office circuit have also been repeated for explanatory purposes. The insertion of the first penny in the coin-collecting box operates contacts ***CB*1** which remove the short circuit from the coin-box transmitter and relay *P*, and also apply a 200 Ω shunt to the telephone receiver. The insertion of the second coin operates springs ***CB*2**, which now extend the 1000 Ω earth via ***CB*1** and ***CB*3** to the *B*-line of the circuit. The earth energizes relay *L* at the exchange, but the current under these conditions is insufficient to operate relay *E*. ***L*1** lights the calling lamp in the usual way.

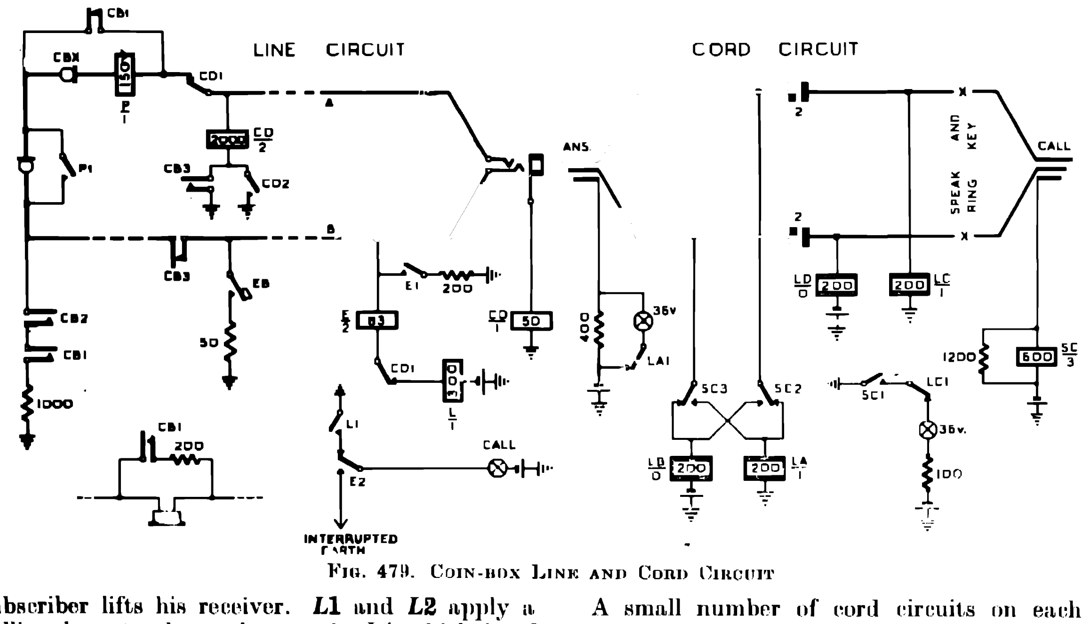


FIG. 479. COIN-BOX LINE AND CORD CIRCUIT

subscriber lifts his receiver. ***L*1** and ***L*2** apply a calling loop to the exchange via *1A* which is of sufficient impedance to be left across the speaking pair without introducing a serious transmission loss.

On calls to the subscriber, ringing current sent out from the cord circuit operates relay *RR*. The 2 μF condenser and impedance *1B* are included in series with *RR* to prevent premature tripping of automatic ringing. ***RR*1** removes the *1A* loop, and ***RR*2** and ***RR*3** repeat the ringing signal to line.

A small number of cord circuits on each A-position dealing with coin-box calls are modified for coin-box working. The cord circuits are essentially similar to the normal cord circuit except that the battery and earth feeds to the answering plug are reversed when the calling plug is inserted into a multiple jack. Fig. 479 illustrates a typical 40 V coin-box type cord circuit. On receipt of a calling signal, the operator inserts the answering plug into the appropriate jack and relay *LA* now

operates over the telephone loop to the battery at *LB*. It will be noted that the direction of this current through relay *P* is such that the polarized relay does not operate. The circuit allows the coin-box user to speak to the operator and to give details of the call required. There is, of course, some degradation of transmission due to the 200 Ω shunt on the call office receiver, but this loss is not serious under the conditions at this stage of the call. After ascertaining details of the number required, the operator tests the required line and inserts the calling plug into a convenient multiple jack. Relay *SC* now operates to the 30 Ω earth on the sleeve conductor, and contacts ***SC*2** and ***SC*3** reverse the connexions of *LA* and *LB* to line. The reversal of line current now operates relay *P*, which at ***P*1** short circuits the transmitter of the coin-box telephone. It is now not possible for the call office user to speak to the called party until the A-button is pressed and the fee is lodged in the cash-box. The operation of the A-button releases contacts *CB*1 and *CB*2, the former restoring the short circuit across relay *P*. The release of *P*1 now enables the calling party to speak and to proceed with the call. If the caller at this stage attempts to regain his money by depressing button *B*, contacts ***CB*3** disconnect the *B*-line circuit and at the same time apply an earth to the call office *CO* relay which is connected to the *A*-line. Relay *CO* locks at ***CO*2** to the battery from the exchange via ***SC*2** and *LB*. At the same time the operation of ***CO*1** releases relay *LA* and the answering supervisory lamp glows continuously until the circuit is restored to normal by the operator withdrawing the calling plug from the called subscriber's multiple jack.

Provision is made for emergency calls to be made without the insertion of coins. The call office user depresses an emergency button (*EB*), which applies a 50 Ω earth to the *B*-line. The current is now sufficient to operate both relays *E* and *L*. *L* is ineffective, but contact ***E*1** provides a holding circuit for relay *E*, which at ***E*2** applies interrupted earth (0·75 sec on, 0·75 sec off) to the calling lamp. The intermittent glow of the calling lamp provides a distinctive signal to the operator that an emergency call is required. Since no coins have been inserted, contacts *CB*1 have not been operated. Relay *P* is therefore short-circuited and the coin-box user can speak irrespective of the direction of the line current, i.e. even when the calling plug is inserted into a multiple jack.

Types of Switchboard. There are four main types of central battery switchboard, viz.:

C.B. No. 1 *type:* with a capacity for up to 10 000 subscribers' lines.

C.B. No. 10 *type:* to cater for up to a maximum of 2800 subscribers' lines (4200 exceptionally).

C.B. No. 12 *type:* a similar switchboard to the C.B. No. 10 but with a series (break jack) multiple.

C.B. No. 9 *type:* a 800-line multiple exchange employing indicators.

The C.B. 9 and C.B. 12 types are now substantially obsolescent for public exchange work.

C.B. No. 10 Type Sections. The C.B. No. 10 type exchange is made up of one-position two-panel sections of 1 ft 11 in. wide. The No. 10 type switchboard employs B gauge plugs and jacks, and the total capacity for subscribers' answering equipment and outgoing junction multiple is twenty-five strips per panel. The outgoing junction multiple is provided on a four- or six-panel repetition basis with jacks in strips of twenty.

The subscribers' multiple arrangements vary at different exchanges. In some cases a four-panel repetition is adopted which, with twenty-five strips per panel, gives a maximum capacity of 2000 lines. By removing the cornice, the panel space for the subscribers' multiple can be increased to thirty-five strips per panel, which with four-panel repetition gives a capacity of up to 2800 lines. The same arrangement with a six-panel multiple repetition gives a maximum of 4200 for the exchange.

C.B. No. 1 Type Sections. The No. 1 type sections are 5 ft 8 in. wide and have eight panels and three positions. One-position two-panel sections, one-position three-panel sections, and two-position six-panel sections are provided for use for exceptionally round bends. The sections are available in two types. The first provides for an ultimate subscribers' multiple of up to 6400 lines, and the second is designed for exchanges having an ultimate multiple of between 6500 and 10 000 lines.

All jacks of C.B.1 switchboards are of the C gauge. The subscribers' answering jacks are in strips of ten with alternate designation labels. The outgoing junction multiple jacks and the subscribers' multiple jacks are in strips of twenty. In the smaller exchanges the A- and B-positions form one suite, and in these circumstances the subscribers' multiple repetition is usually every eight panels. Where separate A and B suites are installed, the subscribers' multiple normally recurs once every eight panels on the A suite and once every six panels on the B suite. Exceptionally, nine panel repetition of the subscribers' multiple is sometimes adopted at exchanges where there is a very high percentage of outgoing junction and trunk calls. In all cases, the outgoing junction multiple recurs once every six panels.

A sectional view of a C.B. No. 1 type section is

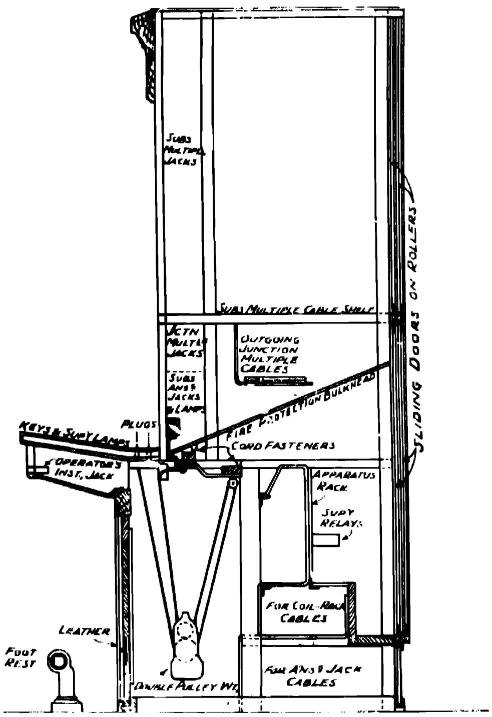


Fig. 480. Section of a C.B.1 Type Switchboard

given in Fig. 480, whilst Fig. 481 shows a typical face equipment. The jack field is divided into two parts by means of ¾ in. spacing strip opposite the subscribers' multiple cable shelf. The upper portion of the panel has a capacity for forty-five jack strips (C gauge) in the 6400-line exchange, and for seventy-two jack strips in the 10 000-line type. The capacity of the smaller type section can, however, be increased to fifty-five jack strips per panel exceptionally to give a maximum multiple of 8000 lines on an eight-panel repetition basis.

Where separate A and B suites are provided, the multiple cable shelf is lowered to increase the vertical multiple capacity on the B suite. A maximum of up to seventy-three strips can be fitted on the 6400-line section, whilst on the 10 000-line type up to ninety-eight multiple jack strips can be accommodated.

Below the multiple cable shelf there is space for thirty-two strips of answering jacks, outgoing junction jacks, etc.

Fig. 482 shows the end portion of a B-suite at a C.B. No. 1 exchange. It will be noted that the end position is not equipped with cord circuits, but is required primarily to make the complete multiple accessible to the operator on the second position. The switchboard illustrated is of the 10 000-line type, and is provided with multiple jacks for 5400 lines on a six-panel repetition basis.

Keyshelf Lay-out. The keyshelf equipment of a subscribers' position is shown in Fig. 483. This illustration indicates the C.B. No. 10 keyshelf, but the arrangement of the No. 1 type keyshelf is very similar. Drillings are provided for a maximum of seventeen pairs of cords, but usually only sixteen cord circuits are fitted. Associated with each cord circuit is a combined speaking and ringing key together with the answering and calling cord supervisory lamps. Behind these are the effective meter keys and at the extreme right of the keyshelf is the ineffective meter key. On the C.B. No. 10 type section provision is made for a

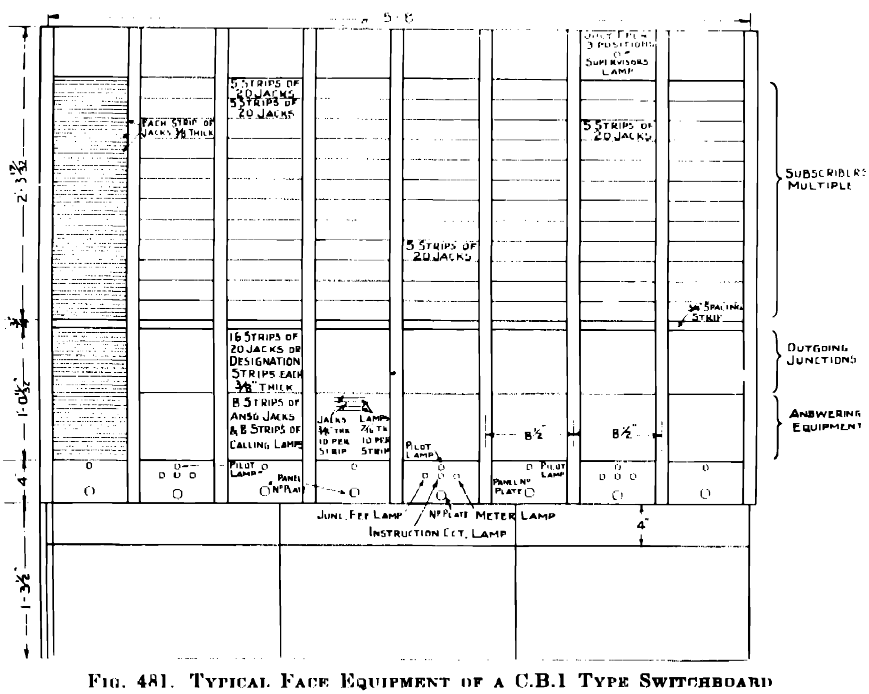


Fig. 481. Typical Face Equipment of a C.B.1 Type Switchboard

maximum of forty order-wire keys in strips of ten, whereas in the C.B.1 type switchboard there is a maximum of eighty order-wire keys. A dial switching key is also provided when dialling into an automatic network is required, and time check keys and lamps are fitted when specified. On plug-ended incoming junction positions there are thirty-three to thirty-six single cord circuits and from ten to forty order-wire keys.

Lay-out of Switchroom. Fig. 484 shows a general view of a typical C.B. No. 10 type exchange. The floor plan of a somewhat larger exchange of the No. 1 type is illustrated in Fig. 485. The lay-out of any particular switchroom depends upon the floor space available, together with the initial and ultimate requirements. It is important to ensure an adequate space behind the switchboard for maintenance purposes, and the lay-out must be such as to provide comfortable sitting space for the telephonists. This is particularly important at bends. The lay-out must also make the maximum possible use of the natural lighting, and should give a compact lay-out throughout the development of the exchange. An emergency exit (often combined with the apparatus entrance) must be arranged in all cases.

It will be noted that each suite commences with a *cable turning section* (abbreviated C.T.S.) which, as its name implies, is necessary to turn the switchboard cables from the vertical run through the floor to the horizontal multiple along the switchboard. The C.T.S. is constructed of mahogany panelled to match the rest of the switchboard. Bends in the suite are negotiated by means of *angle sections* so designed that the required bend is obtained without prejudice to the sitting space of the operators, and to ensure that the whole of the subscribers' multiple shall be available to all operators at the bend. It is usual to provide one unequipped position immediately following the last working position in order to allow the operator on the latter access to a complete multiple. Except where the dimensions of the room prevent further extension of the suite the growing end of each switchboard is terminated by a *cable storing section* (abbreviated C.S.S.). The purpose of this section is to provide accommodation for the "tails" of the switchboard multiple cables. If a switchboard with a large number of multiple circuits is to be extended it is not easy to withdraw the jacks of the last appearance in order to connect in the extended multiple. Moreover, such a course would considerably interfere with operating, and in the past it has been the normal practice to provide tails to the switchboard cables of sufficient length to connect to the next appearance of the multiple on extension. During the interim period the free ends of the cables are suitably insulated by wrapping the end of the tail with tape.

Order of Positions. In small and medium sized C.B. exchanges, the positions are usually arranged

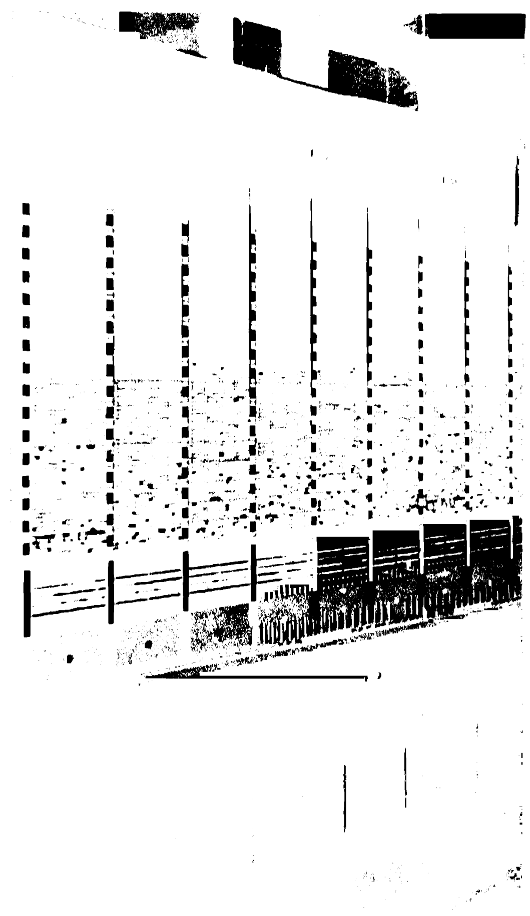


FIG. 482. B-POSITIONS, C.B.1 EXCHANGE.

en suite in the following order from the non-growing end:

Plug-ended B-positions;
Jack-ended B-positions;
Combined jack-ended B- and A-positions;
Subscribers' A-positions;
Test and plugging-up position.

In larger exchanges the provision of a separate suite for the plug-ended B-positions is warranted, and in these circumstances advantage is taken of the segregation to adopt a somewhat shorter span for the subscribers multiple over the B suite.

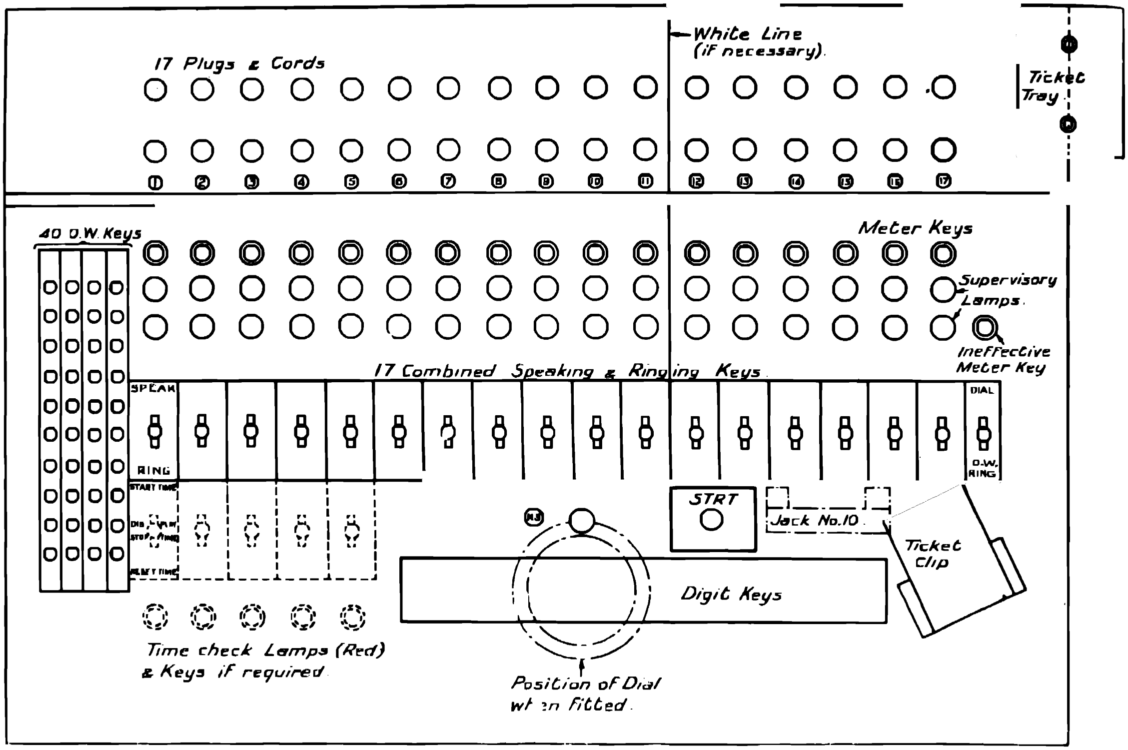


FIG. 483. TYPICAL KEYSHELF LAY-OUT

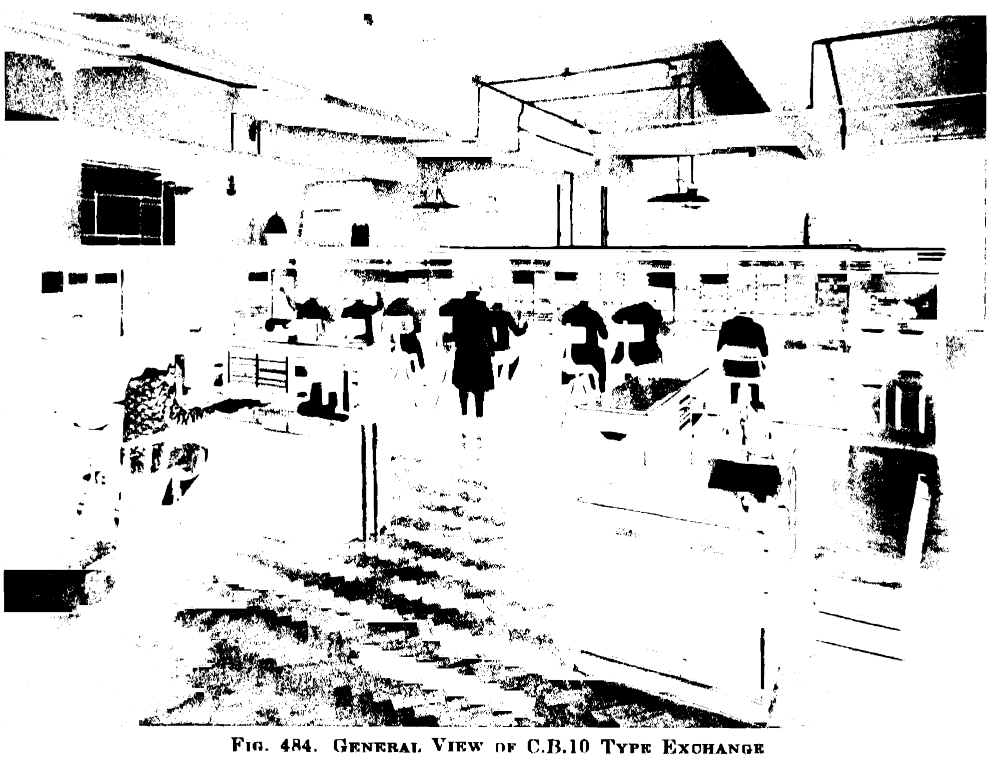


FIG. 484. GENERAL VIEW OF C.B.10 TYPE EXCHANGE

Desks for Supervisory Staff. In all manual switchrooms, desks are required to facilitate the various supervisory duties of the monitors and exchange supervisors. In very small exchanges an ordinary table with a simple telephone instrument is provided. In larger exchanges a small apparatus panel is mounted on a suitable table for the exchange monitor, and a simple telephone is installed on the supervisor's table. At still larger exchanges a monitor's desk of the required number of positions is provided, and a separate one-position desk is installed for the supervisor, whilst in the largest C.B. exchanges there may be several divisional supervisors' desks and one chief supervisor's desk.

Monitor's Desk. The monitor's desk is usually made up of two-position sections, fitted with two panels. The panels contain jack and lamp strips to accommodate various circuits. Normally, monitors' desks are equipped with the following circuits:

(*a*) Listening-in lines to enable the monitor to tap any operator's telephone circuit.

(*b*) Instruction circuits by the use of which the monitor can pass instructions to the operating staff.

(*c*) Incoming and outgoing lines to the switchboard to other desks and to the supervisor.

(*d*) Interception circuits for intercepting calls to and from a subscriber.

(*e*) Speaking and listening test circuits.

The keyshelf provides for up to eight cord circuits with the necessary plugs and cords, supervisory lamps, ringing, flashing, and speaking keys. In some cases order-wire keys are also provided on the monitor's desk. A hinged shelf is provided at the rear of the monitor's desk to provide additional writing space.

Supervisor's Desk. The supervisor's desk is a one-position switchboard with a jack field which accommodates listening-in lines to the monitor's positions and to the ordinary switchboard positions of the A and B suites. Bothway and unidirectional lines are also provided to the switchboard. One cord circuit is provided and is connected to the supervisor's telephone.

Meter Cabinet. It is usual in a large exchange to provide a meter cabinet in the switchroom to accommodate the ineffective and totalling position meters. The meter cabinet is located centrally in the switchroom, usually at the non-growing end of the monitor's desk. In smaller exchanges of the C.B. No. 10 type the position meters are often housed in the cable turning section.

Test and Plugging-up Position. One or more positions at the end of the A suite are specially equipped to enable the operating staff to carry out preliminary tests on lines which are suspected of being faulty. The position also provides facilities for "plugging up" lines proved to be out of order. In addition to the testing and plugging-up facilities the T and P.U. position is also equipped with such miscellaneous testing equipment as:

(*a*) Generator calling equipments from the A and B suite multiples, from the monitor's desk and from the engineering test desk.

(*b*) Test extension lines to and from the engineering test desk and to the end position of the B suite. Order-wire circuits are provided for use in conjunction with the test extension lines. The extension lines are terminated on special plugs at the incoming end and enable the complete switchboard multiple to be tested.

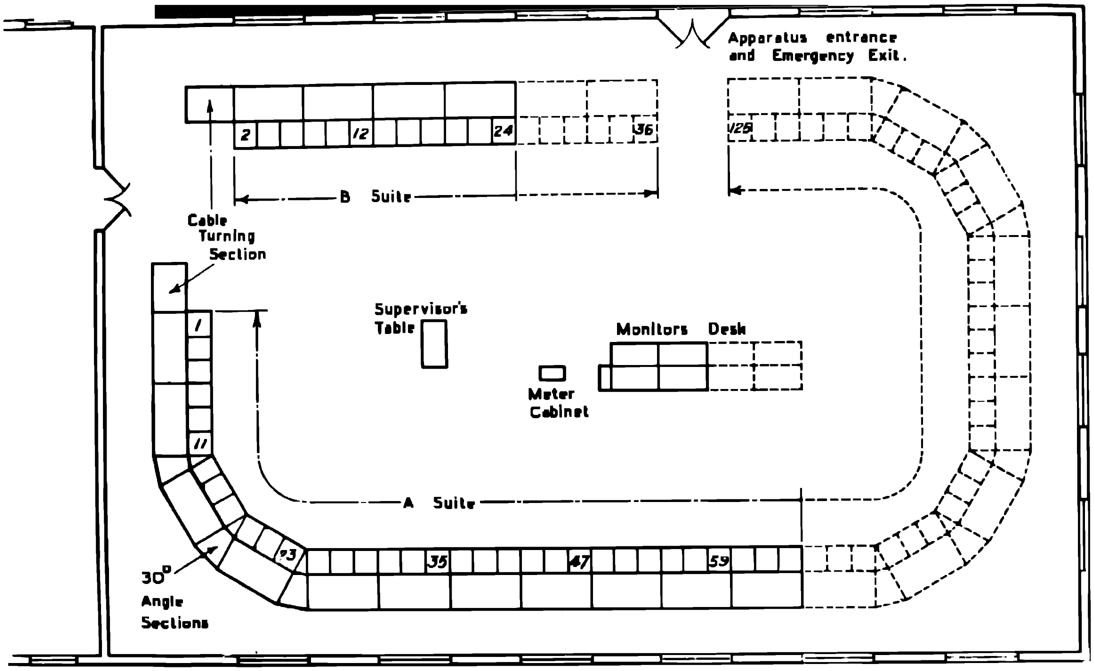
(*c*) A meter test circuit to enable routine functional tests to be made on the subscribers' meters.

(*d*) A howler cord circuit which is used to attract the attention of a subscriber who has left his receiver off the rest.

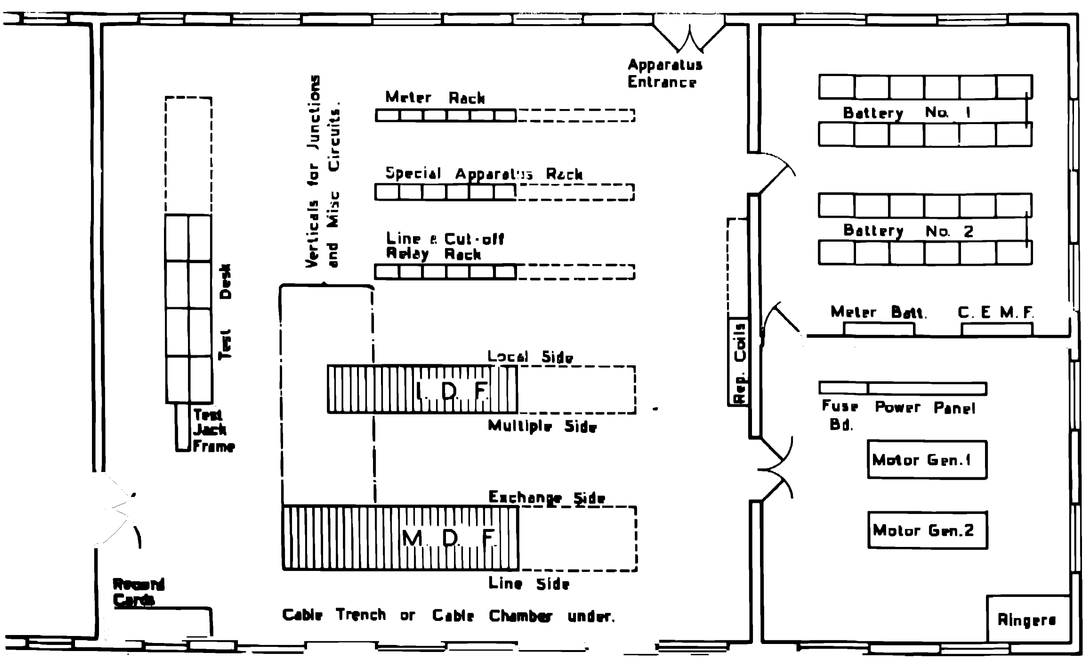
(*e*) A third conductor test circuit to verify the continuity of the sleeve connexion of the subscriber's multiple.

Apparatus Room Lay-out. A typical lay-out of the apparatus room and switchroom of a large C.B. No. 1 exchange is given in Fig. 485. The position of the M.D.F. is determined by the lead-in arrangement of the underground cables and is usually placed parallel to and near an outside wall with the cable trench or cable chamber below it. The I.D.F. is parallel to the M.D.F. whilst the line and cut-off relay rack, the special apparatus rack and the meter rack are arranged as shown. It will be noted that all the frames and racks are designed to grow in the same direction.

The lay-out of any apparatus room is largely determined by the cost and ease of cabling. The standard cabling arrangements of a C.B. subscribers' line circuit are shown in Fig. 486. It will be seen that 84-wire cables are required to serve each group of twenty subscribers' line and cut-off relays, and similar size cables are required to connect the line to the answering equipment on the switchboard. Sixty-three-wire cables are employed for the outgoing multiple, whilst forty-two-wire cables are necessary to link the M.D.F. with the I.D.F. multiple side. (In modern practice the cables would be 80-, 60- and 40-wire respectively.) It is apparent from this illustration that the outgoing multiple jacks are permanently tied at the I.D.F. to specific meters and to particular circuits on the exchange side of the M.D.F. Also, the subscribers'



(a) First Floor—Manual Switchroom.



(b) Ground Floor—Apparatus Room.

FIG. 485. LAY-OUT OF TYPICAL C.B. EXCHANGE

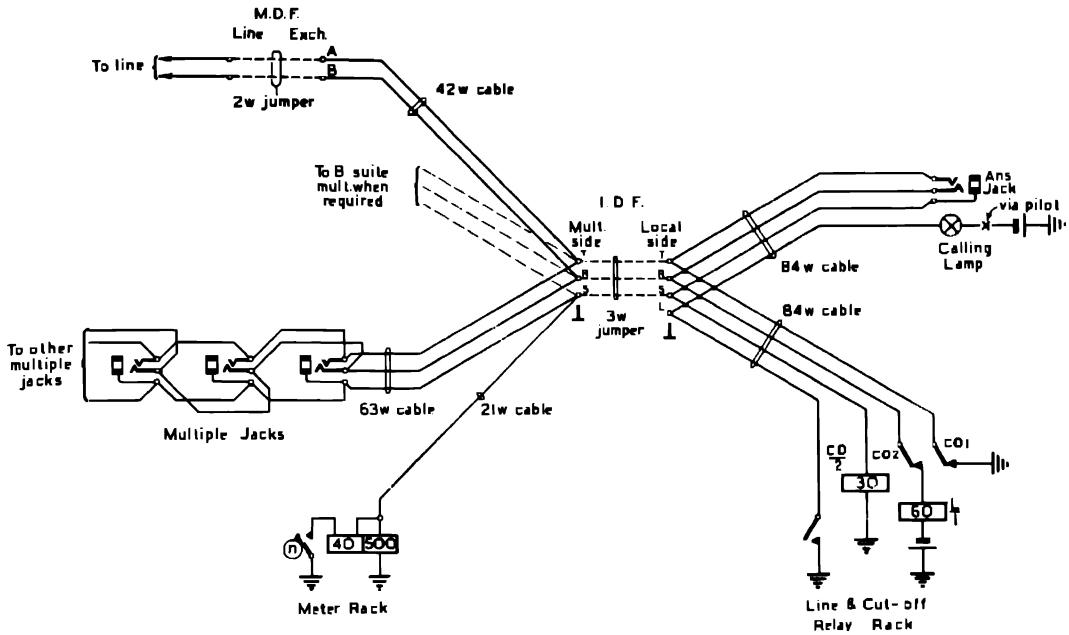


Fig. 486. Cabling Arrangements for Subscribers' Lines

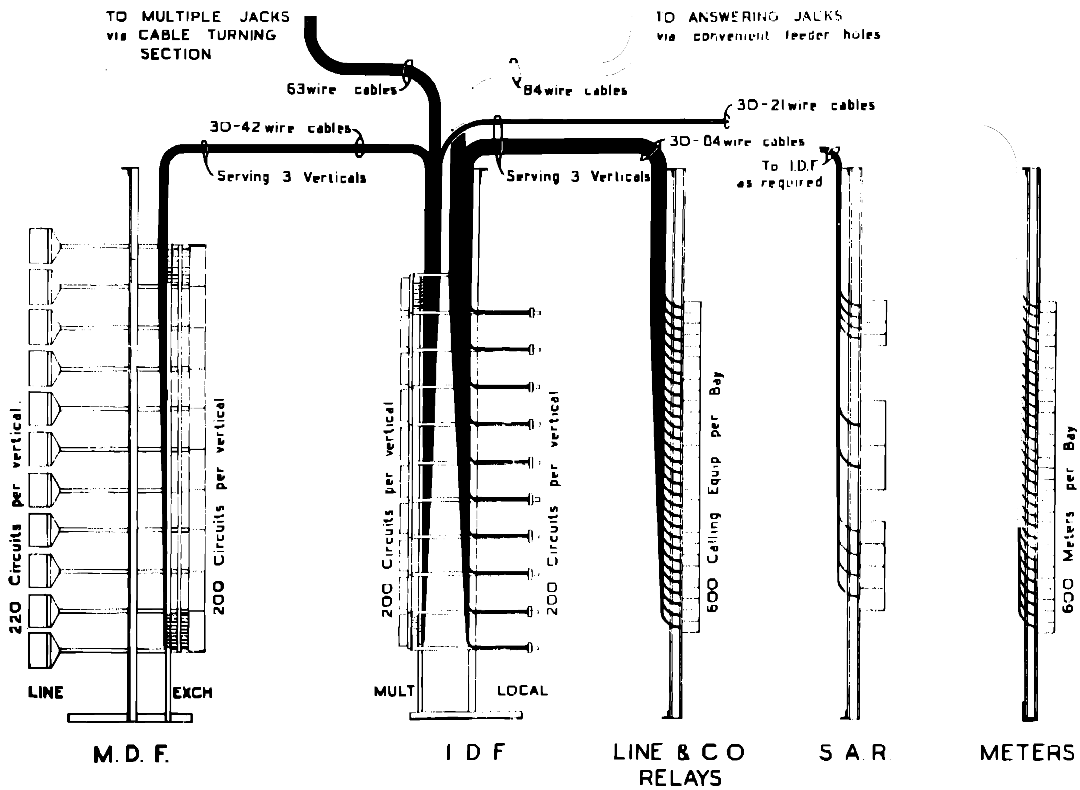


Fig. 487. Cross-section of C.B. Exchange Apparatus Room showing Main Cable Runs
(Thickness of line represents size of cables)

answering equipment is permanently wired at the I.D.F. local to particular line and cut-off relays. Any external circuit can thus be connected to any outgoing multiple circuit by means of a jumper on the M.D.F. and can also be extended to any answering equipment by means of the three-wire I.D.F. jumper.

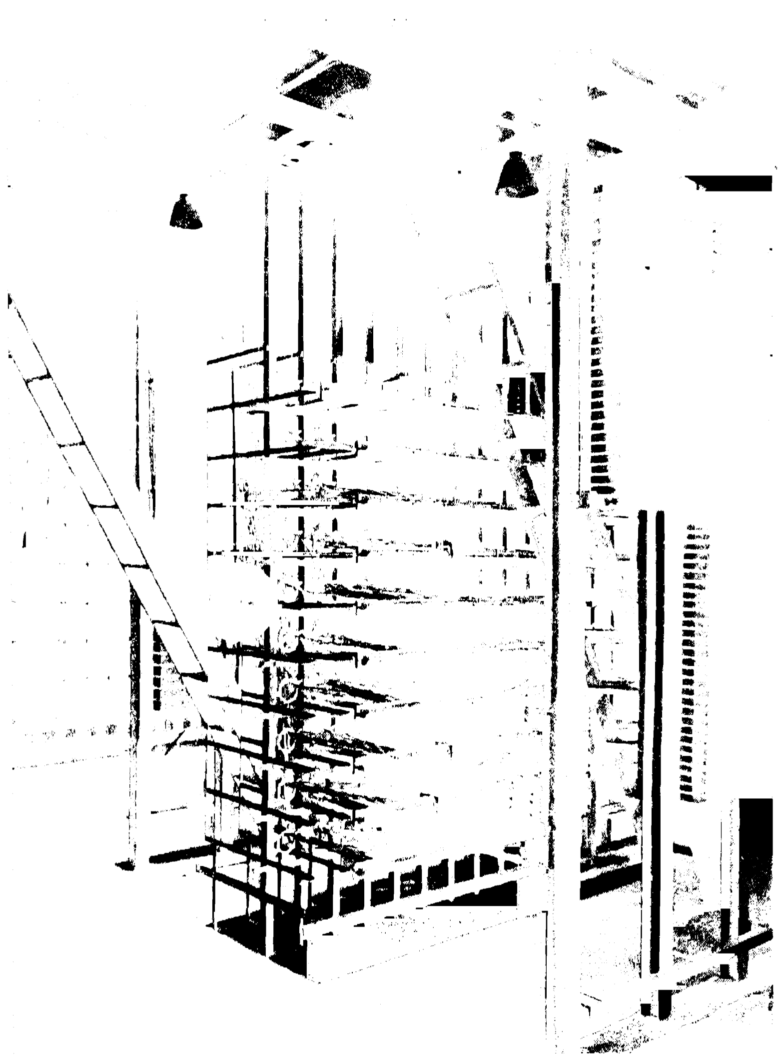


FIG. 488. TYPICAL C.B. EXCHANGE APPARATUS ROOM

Fig. 487 shows a diagrammatic cross-section of a C.B. exchange apparatus room and indicates the general arrangements of cabling for subscribers lines. The line and cut-off relay rack is of the type illustrated in Fig. 438, and accommodates, with flat type relays, 600 subscribers' line and cut-off relays per rack. The meter rack is of similar width and also accommodates 600 subscribers' meters. The M.D.F. and I.D.F. are so designed that three verticals take up exactly the same distance as one apparatus rack. By arranging the M.D.F., I.D.F., and apparatus rack parallel to each other it is therefore possible to adopt a simple form of transverse cabling with units of 600 lines. Thus the three verticals of the M.D.F. are cabled out by means of thirty 42-wire cables to the I.D.F. multiple side, whilst thirty 84-wire cables link the local side of the I.D.F. to the line and cut-off relays. Similarly, thirty cables of 21 wires each serve the associated meter rack. The cables from the multiple side of the I.D.F. to the subscribers' multiple in the switchboard are led by means of overhead runways to a hole in the ceiling immediately below the cable turning section. The cables to the answering jacks are, however, led into the switchboard at the most convenient point or points. In a small or medium sized exchange this point is usually half-way along the length of the suite, but in larger exchanges there may be two or three points of entry to avoid congestion in the switchboard cable run. In some exchanges where line and cut-off relays of a large type are provided, the capacity of each bay is only 300 circuits. In these circumstances two line and cut-off relay racks are arranged parallel to each other, so that the same scheme of 600 circuits for the length of three M.D.F. verticals is maintained. Fig. 488 gives a general view of a C.B. exchange apparatus room. It will be noted that, in this case, the line and cut-off relay rack is located between the M.D.F. and I.D.F. instead of between the I.D.F. and meter rack as shown in Fig. 487. Both lay-outs are common, the exact arrangements in any particular case being determined largely by the relative cabling costs.

The I.D.F. is set back from the non-growing end of the M.D.F. (Fig. 485) and similarly the apparatus racks are further set back beyond the commencement of the I.D.F. There are therefore a number of M.D.F. and I.D.F. verticals which do not line up with the apparatus racks. These verticals are required for the termination of the various junction and miscellaneous circuits. In C.B. No. 10 exchanges a combined M. and I.D.F. is often used and, similarly, combined meter and line relay racks are common.

The test desk is located within convenient access of the M.D.F. and as far as possible from the noise of the motor generators, ringers, etc. In 22 V C.B. exchanges a separate repeating coil rack is provided in the apparatus room for the cord circuit coils. This rack is generally located as near as possible to the power plant in order to reduce the length of the battery supply leads.

EXERCISES XVI

1. Explain clearly the meaning of the term "4-panel multiple" as applied to a manual switchboard.

A central battery manual exchange with multiple equipment for 800 subscribers, has switchboard sections each consisting of one 2-panel position. Give a sketch showing the layout of a 4-panel subscribers' multiple at this exchange, indicating the order of numbering over three adjacent positions, and the relative positions of the subscribers' multiple jacks, the outgoing junction jacks, and the subscribers' answering jacks and lamps.

Show also, by means of a further sketch, how the multiple cables are supported inside the switchboard sections. (*C. & G. Telephone Exchange Systems I*, 1947.)

2. (*a*) Draw a diagram of the connexions of an A-position cord circuit as used in a 40 V central battery manual exchange. Explain, fully, the functions of the impedance coils and the capacitors (condensers) provided in the circuit.

(*b*) What are the general advantages of 40 V working as compared with 22 V working in manual exchanges? (*C. & G. Telephone Exchange Systems I*, 1947.)

3. Explain the functions of the condensers employed in the central battery manual system in (*a*) a subscriber's telephone, (*b*) an A-position operator's telephone circuit. Give circuit diagrams. (*C. & G. Telephony, Grade I*, 1942.)

4. The diagram (Figs. 470, 472, and 477) shows the circuit connexions concerned in the metering of calls from subscribers on a 22 V central battery manual exchange. Describe how the circuit operates when an effective call is being metered, and calculate the values of the currents in (*a*) the 500 Ω coil of the subscriber's meter; (*b*) the total calls meter at each stage of the operations.

Note: The battery and leads are of negligible resistance. The resistance of the 12 V lamp is 120 Ω. (*C. & G. Telephony, Grade I*, 1942.)

5. Draw a diagram of the connexions of a subscriber's line circuit at a central battery manual exchange. Describe the operation of the line circuit on calls to and from the subscriber.

State the reasons for providing facilities for cross-connexion on the main and intermediate distribution frames. (*C. & G. Telephony, Grade I*, 1941.)

6. Describe, with the help of diagrams of the circuit elements concerned, how the busy test is made on a subscriber's circuit at an A-position in a central battery exchange. . . . (*C. & G. Telephony, Grade I*, 1940.)

7. Explain, with the aid of a circuit diagram, how the caller at a coin-box telephone connected to a manual exchange is able to give particulars of the call to the operator, but is prevented from speaking to the called party until button "A" has been depressed. (*C. & G. Telephony, Grade II*, 1944.)

8. A pre-payment coin-box telephone in a public kiosk is connected to a central battery manual exchange. Describe, with reference to a simplified circuit diagram, the arrangements in the kiosk and in the exchange that enable a caller in an emergency to obtain the attention of the exchange operator without inserting coins in the box. (*C. & G. Telephony, Grade II*, 1938.)

9. Draw a diagram to show the cabling of a subscriber's circuit at a central-battery exchange through the distribution frames and protective devices to the answering jacks, the multiple, the apparatus rack, and the meter rack. What do you understand by the term "nine-panel multiple," and what is its relation to the operators' "positions"? (*C. & G. Telephony, Grade I*, 1945.)

10. In the metering circuit of Fig. 477, what is the power dissipated in the 25 Ω resistance? If the resistors available will dissipate 4·5 W without producing a risk of fire, what arrangement of resistors would you employ?

CHAPTER XVII

THE CENTRAL BATTERY SYSTEM: JUNCTION WORKING

Unidirectional Jack-ended Junctions. Possibly the simplest form of junction circuit between two C.B. exchanges is the unidirectional jack-ended junction illustrated in Fig. 489. An operator, on receiving a request for a number on the nearby C.B. exchange, tests in the usual manner for a disengaged circuit in the outgoing junction multiple. If the outgoing junction group is large, group engaged tone or visual engaged signals would probably be provided to facilitate testing. After testing, the operator places a calling plug into the jack of the disengaged junction selected, and the insertion of the plug automatically calls the distant exchange by the battery from the cord circuit which is sent out over the *B*-wire. The 30 Ω resistor takes the place of the *CO* relay in a subscriber's line circuit, and besides providing a circuit for the calling cord supervisory lamp it also gives the correct potential drop required for the engaged test.

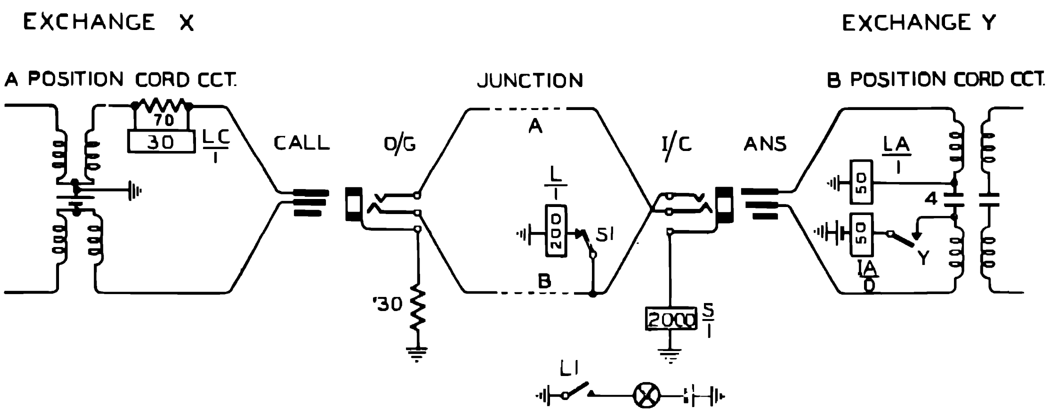


Fig. 489. Unidirectional Jack-ended Junction

The incoming termination of the circuit consists of a line relay *L*, connected to receive the calling battery on the *B*-wire, together with a sleeve relay *S*, which disconnects relay *L* from the line when the call is answered by the incoming operator. It will be noted that the connexions of the *A*- and *B*-wires to the incoming jack are reversed. This reversal is provided in order that when the incoming operator and called subscriber reply (i.e. when contact *Y* closes), battery is sent out from *IA* via the ring conductor of the cord circuit and the *A*-wire of the junction to operate the supervisory relay (*LC*) in the tip circuit of the originating exchange cord circuit.

Jack-ended B-Position Cord Circuit. The ordinary cord circuit used for completing local calls is unsuitable for use on J.E.B. positions owing to the greater facilities required for the handling of junction traffic. The *B*-position cord circuit shown in Fig. 490 is designed to meet the following requirements:

(*a*) Through clearing is provided on junction calls, i.e. a supervisory signal from the called subscriber's switch-hook is passed through the cord circuit and over the junction to operate the cord circuit supervisory lamp at the originating exchange.

(*b*) A supervisory signal is given to the originating operator when the *B*-position operator answers by throwing her speak key; thereby informing the A-operator that the incoming telephonist is listening.

(*c*) The cord circuit is highly balanced to avoid the introduction of noise on junctions.

(*d*) The circuit performs as an ordinary A-position cord circuit when it is used to answer a call from a local subscriber. This facility is desirable so that an operator on a J.E.B. position can, during periods of light traffic on the junction routes, assist adjacent A-position operators in dealing with calls from subscribers.

The change-over from ordinary to through signalling conditions is obtained by means of a

pair of relays (*HR* and *HJ*) in the sleeve circuit of the answering cord. The normal resistance of the bush circuit of a subscriber's line is 30 Ω and, when the answering plug is inserted into such a line, the current is sufficient to allow both *HR* and *HJ* to operate. ***HJ*1** short-circuits contacts *LD*1 and the auxiliary Speak key contacts (*SK*3). The cord circuit therefore behaves exactly as an ordinary A-position cord circuit.

Incoming junctions have the bush of the answering jacks connected to relays of 2000 Ω resistance same time shunts the calling cord supervisory lamp. ***LD*1** in turn again sends out battery on the ***A*-wire** to darken the supervisory lamp at the distant exchange. When the called subscriber replaces his receiver at the end of the call, *LC* releases, *LD* releases and the associated supervisory lamp glows. *LD*1 removes the battery on the *A*-wire and thus gives a clearing signal to the A-operator. When the latter receives a similar clear from the calling subscriber, she takes down the connexion and the removal of the plug from the outgoing junction

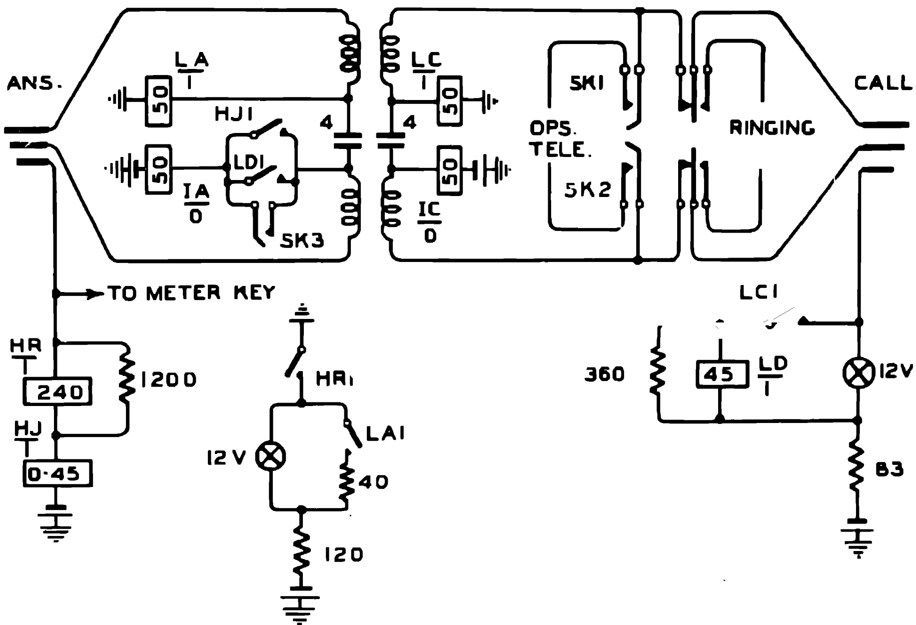


FIG. 490. JACK-ENDED B-POSITION CORD CIRCUIT

(see Fig. 489). When the answering plug is inserted into an incoming junction, the current is sufficient to operate relay *HR*, but is not great enough to energize the 0·45 Ω relay *HJ*. ***HR*1** completes a circuit for the supervisory lamp but, almost at the same time, relay *LA* operates from the calling battery received on the *B*-wire and the supervisory lamp is shunted at ***LA*1**. When the operator throws her speaking key to answer, contacts ***SK*3** close and return battery over the ring conductor (and *A*-wire of the junction) to darken the calling cord supervisory lamp at the originating exchange. In due course the connexion is completed, the required subscriber rung and the speaking key restored to normal. On the restoration of the speaking key a clearing signal is given to the originating exchange until such time as the called subscriber answers. Relay *LC* then operates to the loop. ***LC*1** completes a circuit for *LD* and at the jack allows relay *LA* to release. The restoration of *LA*1 removes the shunt from the B-position answering cord supervisory lamp and the B-operator now breaks down the connexion.

Bothway Jack-ended Junction. Jack-ended junction working is particularly applicable to small groups of junctions and it is therefore usual to operate such circuits on a bothway basis. Fig. 491 shows a termination of a bothway jack-ended junction employing C.B. signalling principles. Normally the junction is switched to the incoming jack and the usual *L* relay and high resistance sleeve relay (*SA*) are provided. If the junction is seized for an incoming call, **L1** operates relay ***ET***, which at ***ET*1** applies a 1000 Ω battery to engage the outgoing multiple. When the operator answers, *SA* operates and at ***SA*2** takes over the holding circuit of the *ET* relay to maintain the engaged condition on the outgoing multiple. By this arrange-

ment the outgoing multiple is engaged from the moment the junction is first seized until the connexion is completely cleared at both ends of the circuit—irrespective of the order in which the plugs are removed.

On outgoing calls the operation of relay *S*, when

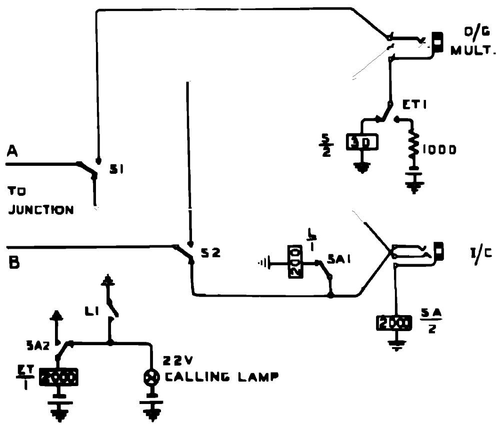


FIG. 491. BOTHWAY JACK-ENDED JUNCTION

a plug is inserted in an outgoing multiple jack, switches the junction at *S*1 and *S*2 and the engaged condition is obtained by the potential drop in the *S* relay.

Differential Signalling Junction. If the line resistance is too great to permit standard C.B. signalling, jack-ended junctions may be worked on a differential signalling basis. The principles of differential signalling have been explained i Chapter XIII, whilst the connexions of a typic bothway circuit for use at C.B. exchanges are give in Fig. 492.

The insertion of a plug into the outgoing jac completes a circuit for relay *M* via contacts *LO* and *LL*1. ***M*1** provides an alternative circuit fo *M* in anticipation of the operation of *LO*2 and *LL*1 The second contact, ***M*2**, operates relay *LO*, which at ***LO*3** energizes relay *LL*. In addition to the operation of relay *M* over the sleeve circuit, the insertion of a calling plug in the outgoing multiple sends out the usual battery on the ring conductor from the cord circuit. This battery operates relay *LC* to the earth at *S*1. Contact ***LC*1** in turn sends out battery over both junction wires in parallel, resistance *y* being so adjusted that *DR* does *not* operate owing to equal currents in its two windings. Resistance *x* is chosen to limit the line current in all cases to a maximum value of 20 mA in order to avoid saturation of the *DR* relay on junction routes of low resistance.

At the incoming exchange, the current received over the *A*- and *B*-wires is combined at the impedance *IL* and operates relay *DR* on one winding to the earth at *LC*1. ***DR*1** operates the relief relay *L*, which at ***L*4** energizes *LL*. ***L*2** takes over the circuit of *S*1 in readiness for the operation of relay *S*. ***L*1** prepares the circuit for the operation of the cord circuit supervisory relay; ***L*3**

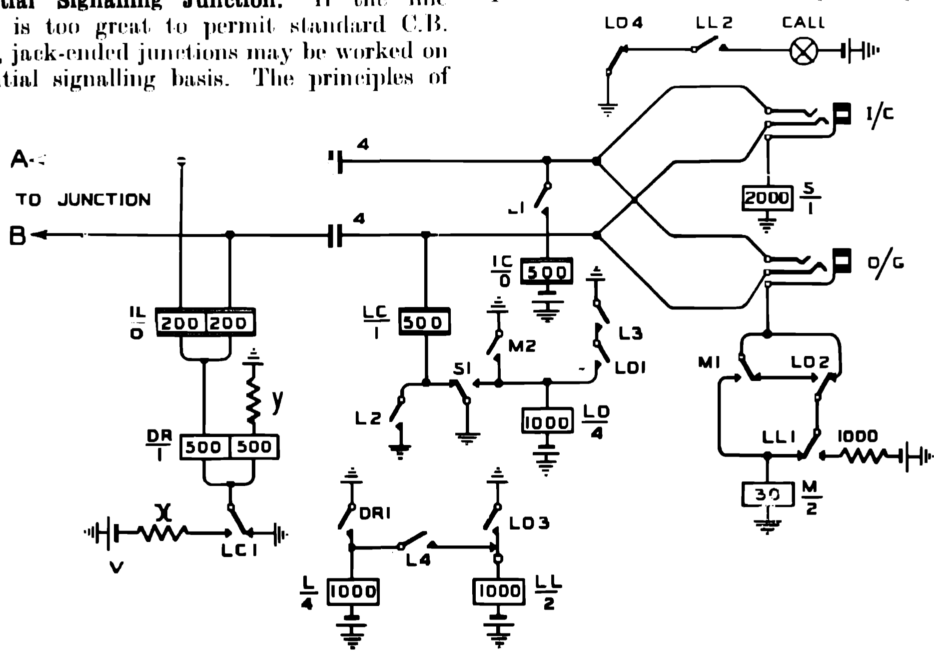


FIG. 492. BOTHWAY DIFFERENTIAL SIGNALLING JUNCTION

prepares a holding circuit for *LO*. **LL1** engages the outgoing multiple, whilst **LL2** lights the calling lamp.

When the incoming operator answers, relay *S* operates and at **S1** completes a circuit for relay *LO*, which locks to its own contact **LO1** under the control of **L3**. **LO2** maintains the engaged condition on the outgoing multiple via *M*1. **LO3** takes over the control of the *LL* relay and **LO4** disconnects the calling lamp. The battery returned on the ring conductor operates *LC* to the earth at **L2**, and **LC1** in turn replaces the earth at the *DR* relay by a battery. Under these speaking conditions, the line current is reduced to zero due to the opposing effects of the signalling batteries, the *DR* relays being held by the current in their second or local windings. At the end of the conversation the called subscriber replaces his receiver and the clear is passed through the B-cord circuit to release relay *LC*. *LC*1 replaces earth to line and thereby allows the distant *DR* relay to release by the balance of current in its two windings. *DR* releases *L*, and *L*1 in turn allows the calling cord supervisory lamp to glow. The originating exchange operator withdraws the calling plug from the junction and, by the release of *LC*, again neutralizes the line current to re-operate the distant *DR* relay until the connexion at that end also is removed.

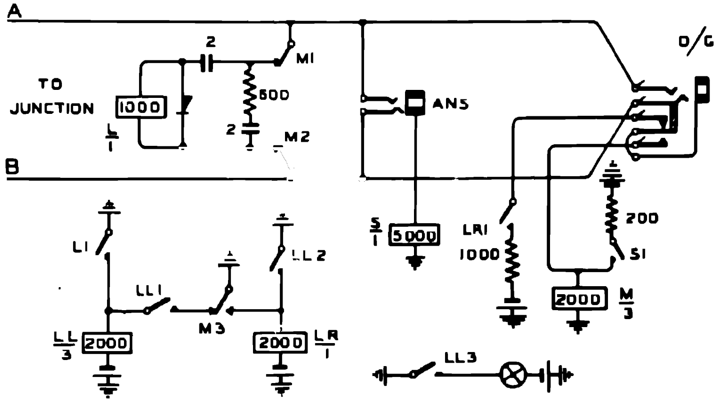


FIG. 493. BOTHWAY GENERATOR SIGNALLING JUNCTION

Generator Signalling Junction. When the line resistance does not permit the use of automatic d.c. signalling, junctions between C.B. exchanges must be worked on a generator signalling basis. Fig. 493 shows a typical bothway circuit. Relay *L* operates on an incoming call and at **L1** operates *LL*. **LL1** provides a holding circuit for *LL* whilst **LL3** lights the calling lamp. **LL2** operates *LR* which at **LR1** applies engaged test battery to the outgoing multiple. When the operator answers, relay *S* operates to the battery on the sleeve of the plug and at **S1** energizes relay *M*. **M1** and **M2** remove the line relay from the speaking pair, whilst **M3** releases *LL* and provides an alternative holding circuit for *LR*. There is no automatic clearing and the cord circuit supervisory lamp glows continuously until the plug is removed from the junction jack.

On outgoing calls, relay *M* operates to the sleeve circuit battery via the auxiliary jack springs. **M1** and **M2** disconnect the calling relay, whilst **M3** energizes relay *LR*. **LR1**, as before, applies engaged test battery to all other multiple appearances. The generator calling current is applied to line direct from the cord circuit.

Plug-ended Keyless Order-wire Junction (22 V). As already explained, jack-ended junction working is unsuitable for large junction groups. With such groups, order wire working is often adopted and the junctions are plug-ended at the incoming exchange. Fig. 494 shows a plug-ended incoming order-wire junction suitable for use in a 22 V exchange. On receipt of a call to be completed over an order-wire junction route, the A-operator depresses the appropriate order-wire key on her position and requests the incoming B-position operator for the number required. The latter assigns the free junction which is to be used and the A-position operator completes the connexion at her exchange by placing the calling plug into the multiple jack of the assigned junction. The outgoing multiple of routes worked on an order-wire basis are not, of course, provided with group engaged tone or other aids to assist testing, but it is usual to provide the normal click engaged test to guard against an engaged circuit being accidentally taken up. Each outgoing junction has therefore the usual 30 Ω resistance spool connected to the sleeve circuit, but otherwise there is no equipment at the outgoing end. The B-position operator takes up the plug of the assigned junction and tests the required line in the usual manner. In order to associate the operator's telephone circuit with every incoming junction cord circuit it is arranged that the tip connexions of all free plugs are connected to the operator's telephone circuit (via *S*2). If the required line is free, the junction plug is inserted into the jack and relay *S* operates to the earth at the subscriber's cut-off relay. **S1** completes a circuit for the *R* relay which also operates to the same earth in the sleeve circuit of the called line.

The operation of ***S*1** also shunts the cord circuit supervisory lamp with the 40 Ω resistance of *R*. ***S*2** changes over the tip circuit of the plug from the operator's telephone circuit and connects the A-line through for conversation. Contacts ***R*1** and ***R*2** apply ringing current and ringing return battery to the tip and ring conductors respectively. In series with the ringing supply to the tip circuit is a relay *F* which is slugged to make it inoperative to alternating ringing current. The ringing current is interrupted in the usual cycle of 0·4 sec on, 0·2 sec off, 0·4 sec on, 2 sec off, and owing to the high impedance of the bell circuit in the subscriber's instrument the current is insufficient to energize *F*. When, however, the called subscriber replies, the impedance of the circuit is considerably reduced and, moreover, there is now a circuit for direct current to flow from the earth at the generator through the *F* relay back to battery via the 40 Ω resistance in the ring circuit. The *F* relay now operates and at ***F*1** allows relay *RC* to operate in series with relay *R*. *RC* has one contact (***RC*1**) which short-circuits *R*. The release of *R*1 and *R*2 disconnect the ringing supply to line and connect the called subscriber through to the transmission bridge. The subscriber's loop now allows the operation of relay *LA*, which at ***LA*1** returns battery over the A-wire of the junction to darken the cord circuit supervisory lamp at the originating exchange.

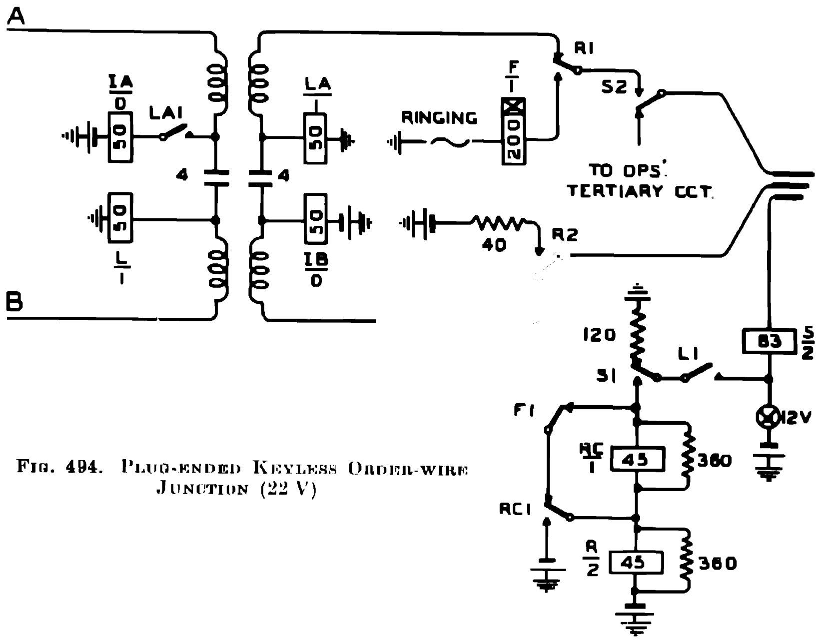


Fig. 494. Plug-ended Keyless Order-wire Junction (22 V)

At the termination of the call, the called subscriber hangs up, and the release of *LA* allows the supervisory lamp associated with the calling cord at the originating exchange to glow. The operator on receiving a similar clearing signal from the calling subscriber, removes the plug from the outgoing junction jack and, by so withdrawing the battery on the *B*-wire, allows relay *L* to release. The release of *L*1 removes the 40 Ω shunt from the cord circuit supervisory lamp and the B-operator then takes down the connexion.

The circuit is so arranged that if an A-position operator does perchance take up a wrong junction, the operation of relay *L* on a free unassigned junction lights the supervisory lamp on the B-position, so drawing attention to the fact that the wrong junction has been taken up. In certain small exchanges it is not economical to run the ringing machine continuously, and in such exchanges arrangements are made for the automatic starting of the ringer by the inclusion of a 1·25 Ω motor start relay in the sleeve circuit of the junction plugs. An additional *RC* break contact is arranged to disconnect the motor start relay when the called subscriber replies.

Plug-ended Keyless Order-wire Junction (40 V). Fig. 495 shows a similar plug-ended keyless order-wire junction as used at 40 V exchanges. In this circuit the insertion of a junction plug into a subscriber's multiple jack allows the operation of relay *S* which at ***S*2** completes a circuit for the *R* relay from the battery at ***L*1**. ***S*3** prepares a circuit for the subsequent operation of the supervisory lamp. ***R*1** and ***R*2** apply ringing current to the called line whilst ***R*3** prevents the premature operation of the supervisory lamp. When the called subscriber replies, relay *F* operates and at ***F*1** removes the short circuit from the *RC* relay which now operates in series with relay *S*. ***RC*2** disconnects the circuit of the *R* relay which releases to switch the tip and ring conductors through for conversation. ***RC*3** takes over the function of *R*3. In other respects this circuit is very similar to the 22 V arrangement.

Order-wire and B-position Telephone Circuit. The outgoing order-wires are multipled throughout all positions at the originating exchange, and any operator can associate her telephone circuit with an order-wire by depressing the appropriate key on her position. The circuit (Fig. 496) is so arranged that the depression of any order-wire key on the position operates relay *CO* which at ***CO*1** and ***CO*2** disconnects the operator's telephone circuit from the cord circuits so that the waiting subscriber shall not be confused by the request on the order-wire. Certain order-wires are to exchanges outside the unit fee area, and to remind the operator that an additional fee is to be charged, such order-wire keys are connected to a second relay *JF*. ***JF*1** operates *CO* to isolate the telephone circuit but a *junction fee lamp* accommodated in the lamp rail glows whenever a fee order-wire key is depressed.

The incoming termination of an order-wire on a plug-ended B-position is shown in Fig. 497. The depression of an order-wire key at the originating exchange places a loop on the order-wire from the secondary of the operator's circuit. (The connexions to the order-wire keys are taken from the induction coil side of the 2 μF condenser.) The loop operates relay *L* which at ***L*1** completes the circuit for the order-wire calling lamp if the position is not staffed (i.e. if relay *PR* is not operated). A busy tone relay (*E*) is operated if the B-position operator leaves the incoming order wire to pass a request over an outgoing order-wire route. Relay *E* is operated by any of the outgoing order-wire keys on the position and at ***E*1** and ***E*2** connects a continuous 400 c/s busy tone to the incoming order-wire. In other respects the telephone circuit is similar to the A and J.E.B. position circuits except for the provision of the additional induction coil required for engaged test purposes. One winding of this coil is connected directly across the operator's receiver, and the other is in series with an earthed circuit to the tips of all incoming junction plugs. If, on making the usual test for the engaged condition a battery potential is encountered, a current flows in the 200 Ω winding to earth, and a corresponding e.m.f. is induced in the receiver circuit.

Order-wire Break Jacks. It will be apparent that the correct functioning of any group of junctions worked on an order-wire basis depends upon the proper working of the circuit used as the order-wire. In order to prevent a complete group of circuits from being thrown out of service in the event of an order-wire becoming faulty, arrangements

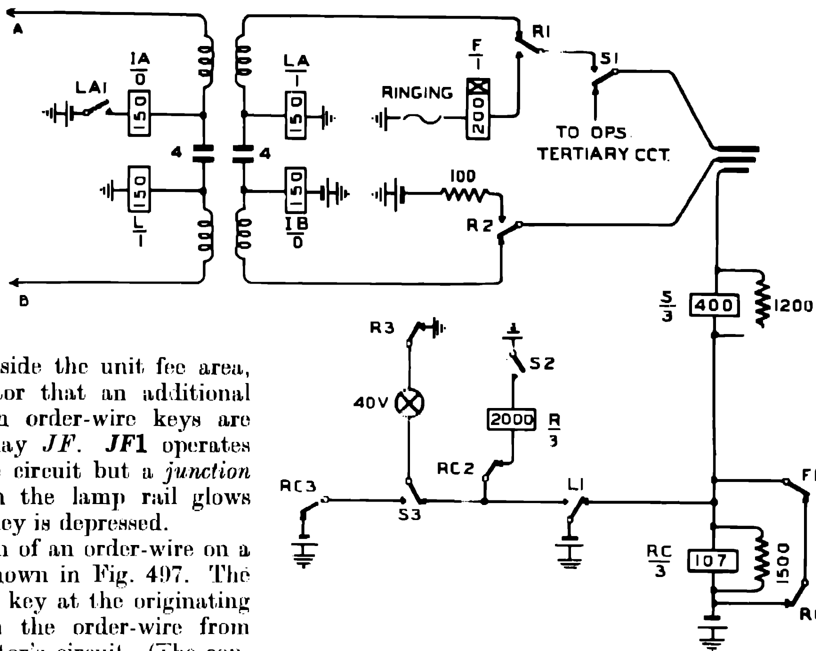


FIG. 495. PLUG-ENDED KEYLESS ORDER-WIRE JUNCTION (40 V)

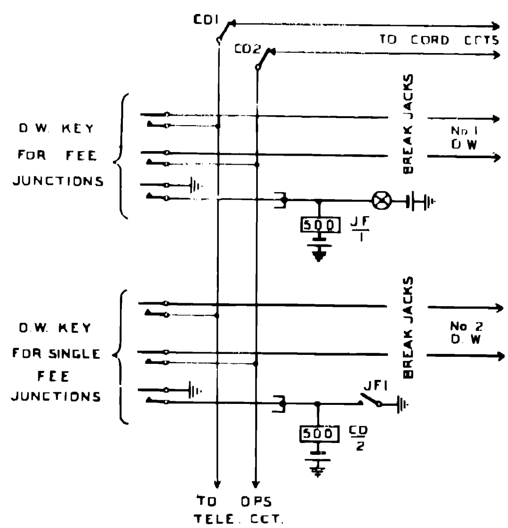


FIG. 496. OUTGOING ORDER-WIRE CIRCUIT

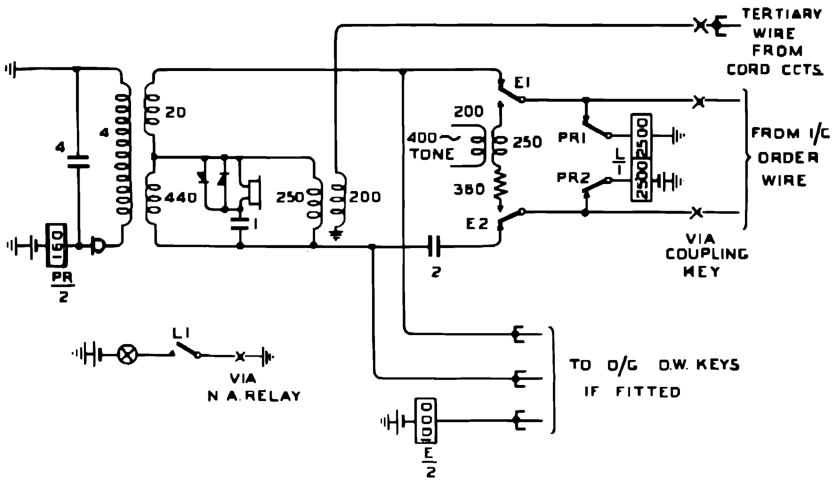


FIG. 497. B-POSITION TELEPHONE CIRCUIT

Circuit for Tripping Automatic Ringing. Plug-ended junctions provided with keyless ringing may be extended over other outgoing junctions which are equipped for signalling on a d.c. basis. It is necessary, therefore, to provide equipment to trip the automatic ringing on all such outgoing junctions which appear over the plug-ended B-positions. The tripping circuit (Fig. 500) is somewhat complicated by the requirements on straightforward junction working (q.v.) that the ringing

are invariably made at both the outgoing and incoming ends of the order-wire to take into use one of the normal junction circuits temporarily as an order-wire in the event of failure of the latter. At the outgoing exchange all order-wires are taken through a pair of break jacks. A number of special connecting cords are provided to isolate the order-wire keys from a faulty order-wire, and to replace the order-wire by a previously chosen junction (Fig. 498). Similarly, each incoming B-position at the distant exchange is provided with special break jacks through which the incoming order-wire is connected, and by placing the plug of the pre-chosen junction into the order-wire break jack, that junction is made to function as an order-wire until such time as the normal order-wire is again available for service (Fig. 499).

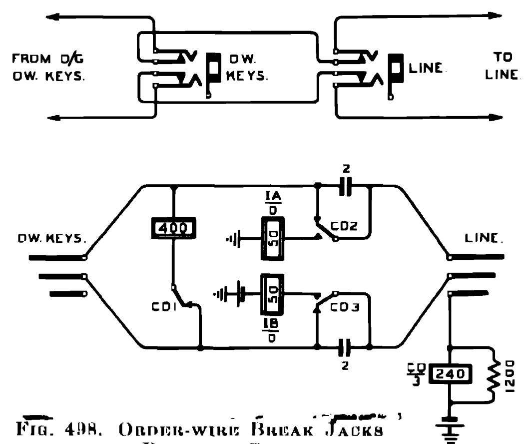


FIG. 498. ORDER-WIRE BREAK JACKS AND PATCHING CORDS

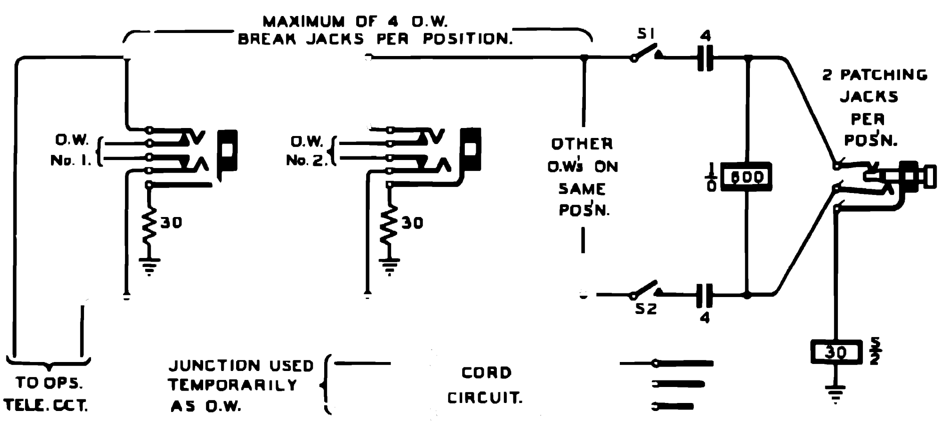


FIG. 499. PATCHING JACK AT INCOMING END OF ORDER WIRE

should be tripped before the calling signal is sent out in order to ensure that the "two-pip" signal returned to the originating exchange is not lost.

Relay *RT* is provided with a slug and is so connected that it will not operate until ringing current has been cut off from the cord circuit. If the outgoing junction is seized during the silent period of ringing, the ring-trip relay of the cord circuit and relay *RT* operate in series, but the slug on *RT* ensures that the former operates first. If, on the other hand, the circuit is seized *during* ringing, a low-impedance circuit is provided to trip the cord circuit relay, but *RT* does not operate until the ringing is cut off. The peak current of negative half-cycles is shunted from the 200 Ω winding of *RT* by *YB* and *MRB* in series, whilst during positive half-cycles the current in the 20 Ω winding balances out the effect of the current in the 200 Ω winding, *YA* providing at all times a circuit for tripping the cord circuit relay.

Straightforward Junction Working. The principle of this method of communication between exchanges has already been discussed in Chapter XII. Briefly, the operating procedure with straightforward junction working between two C.B. exchanges is as follows:

(*a*) The originating operator, on receiving a request for a call to a nearby C.B. exchange, selects in the outgoing multiple a free line to the exchange required. Group engaged tone, free line signals, or visual engaged signals may be provided if the size of the junction group is sufficient to justify these aids.

(*b*) The insertion of a calling plug into an outgoing jack seizes the appropriate cord circuit on a plug-ended B-position at the distant end.

(*c*) The calling signal lights the supervisory lamp associated with the cord circuit, and also causes a cord circuit finder to rotate and extend the cord circuit to the B-position operator's telephone.

(*d*) Immediately a cord circuit is connected to the operator's telephone, the continuous glow of the supervisory lamp changes to a flashing signal to advise the B-operator of the circuit to which she is connected. At the same time, a signal consisting of two "pips" of 900 c/s tone is returned to the originating exchange to indicate that the incoming operator is listening.

(*e*) The originating A-operator passes her demand over the junction.

(*f*) If the required line is free, the B-operator completes the connexion and the called subscriber is automatically rung from the cord circuit.

(*g*) If the required line is engaged the operator depresses the Busy key on her position and busy tone and flash are returned to the calling exchange.

(*h*) The insertion of a plug into a multiple jack, or the depression of the busy key, dissociates the cord circuit from the operator's position circuit which is then free for dealing with calls on other junctions.

(*i*) A Junction Release key is provided on each B-position in order that the operator can release her position circuit from any junction where, on account of fault conditions, or due to inattention of the originating operator, the calling signal is not followed by a request for connexion.

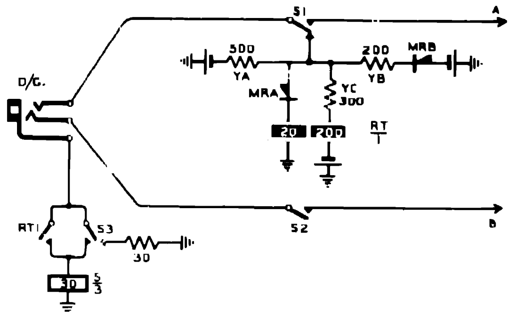


FIG. 500. TRIPPING CIRCUIT FOR AUTOMATIC RINGING

The S.F.J. positions are, apart from the addition of the Busy and Junction Release keys, identical with the normal plug-ended order-wire B-positions. Thirty-six cords are provided per position, and since the standard uniselector has only twenty-five outlets, two cord circuit finders are provided—one serving cord circuits 1–18 and the other serving 19–36. The trunking arrangements of straightforward junction working without distribution are given in Fig. 501.

Before considering the detailed cord and position circuits, it is desirable to examine several new circuit elements which are utilized in the complete circuits.

Coupling of a Calling Junction to the Position Circuit. Fig. 502 shows the circuit elements which control the hunting for a calling cord circuit and the subsequent switching to the position circuit. The upper portion of the figure shows the equipment individual to a particular cord circuit, whilst the lower half shows equipment common to the position. The calling signal on the B-wire of the junction operates (indirectly) a relief relay *LL* which at *LL4* applies an earth to the common *C*-wire and at *LL1* removes the earth from a particular contact on the *P* bank of the uniselector. All other contacts on the *P* bank are earthed either by the earth

from *LL4* via the common start wire if the circuit is free, or alternatively from the circuit's own *LL4* contact via *CL2* if the circuit is engaged.

The application of an earth to the start wire (*C*) operates *SC* which at *SC1* applies the switching relay *K* to the *P*-wiper. At the same time the

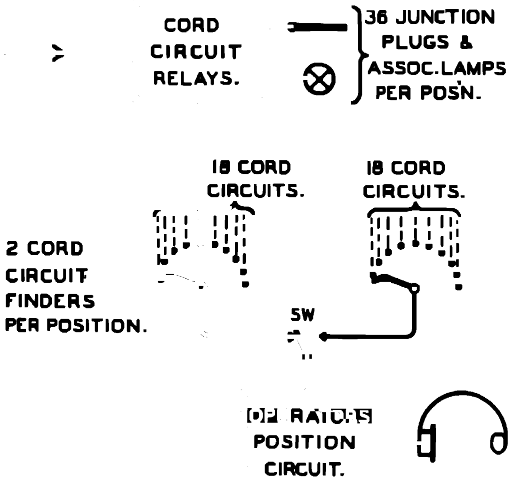


Fig. 501. S.F.J. Working Without Distribution

application of the earth on all free positions of the *P* arc (except that of the calling junction) causes the uniselector to step under the action of its own interrupter contacts (*dm*). The absence of an earth on the contact corresponding to the calling junction prevents further energization of the uniselector driving magnet, and also removes the short circuit from the *K* relay which now operates from the *DM* battery. **K4** provides a locking circuit for *K* and isolates the driving magnet, whilst other contacts of the *K* relay switch the speaking conductors, etc., of the position circuit through to the cord circuit.

When the required connexion has been set up, *CL* operates from the conditions on the sleeve circuit of the multiple jack and *CL2* removes the earth from the common start wire and applies earth to the contact of the *P* bank for the duration of the call (i.e. until *LL* releases).

The application of the earth on the *P* bank again short-circuits the K relay which, in releasing, allows the uniselector to rotate to the first disengaged cord circuit in readiness for the next call.

In a similar manner, the depression of the Junction Release key operates *MR* which at *MR1* steps the uniselector driving magnet to free the position circuit from a junction.

Return of " Pip-Pip " Tone. Fig. 503 shows the conditions when the uniselector has switched to a calling junction. The *LO* relay of the position circuit operates from the battery and earth of the cord circuit transmission bridge. At *LO1*, 400 c/s tone is applied to line. *LO4* operates relay *TA* which, after its slow-to-operate period, breaks the tone circuit at *TA1*. *TA2* completes the circuit for *TB* which is also slow to operate, and after a short pause the tone is reapplied at *TB2*. *TB1* operates the *TC* relay (also slow to operate by virtue of its short-circuited winding) whilst *TC2* and *TC3* remove the tone and switch the speaking pair through to the operator's telephone circuit. *TC5* releases *TA* and *TB* and locks the *TC* relay until *LO* releases when the call is set up.

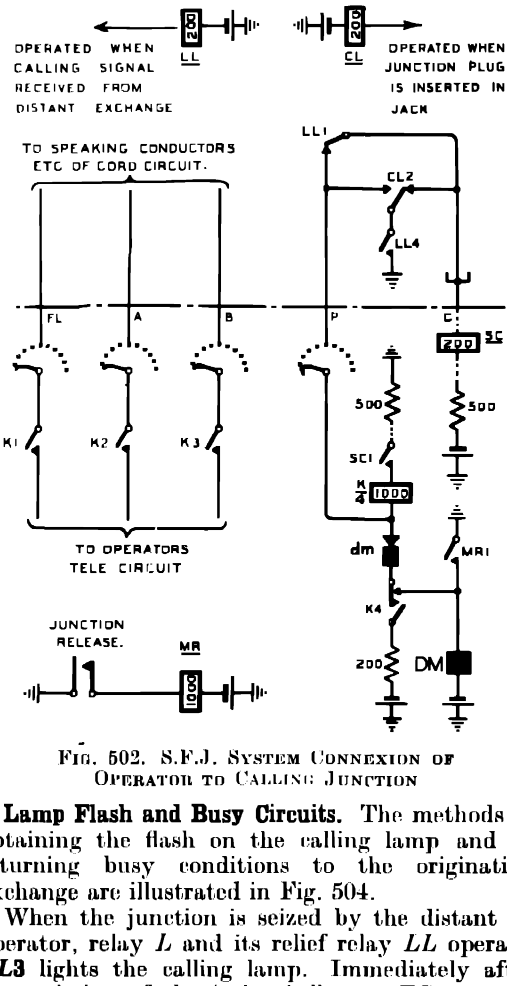


Fig. 502. S.F.J. System Connexion of Operator to Calling Junction

Lamp Flash and Busy Circuits. The methods of obtaining the flash on the calling lamp and of returning busy conditions to the originating exchange are illustrated in Fig. 504.

When the junction is seized by the distant A-operator, relay *L* and its relief relay *LL* operate. *LL3* lights the calling lamp. Immediately after transmission of the "pip-pip" tone *TC* operates (Fig. 503) and at *TC4* applies interrupted earth (0·75 sec on, 0·75 sec off) via the 1200 Ω resistance

to the *FL* wire. Relays *BB* and *FL* of the cord circuit are connected in series, but only the latter operates owing to the limited value of the current. ***FL*1**, operating in synchronism with the flash contact ***IE*1**, alternately disconnects and lights the supervisory lamp.

If the required line is engaged, the operator depresses the "busy" key which in turn applies a *full* earth to the *FL* wire. Both the *BB* and *FL* relays now operate but the contacts of *FL* are rendered ineffective by the *BB* contacts. The *BB* relay locks at ***BB*4** for the duration of the call and at ***BB*2** and ***BB*3** returns busy tone and flash to the originating exchange, the flash condition being repeated by the alternate operation and release of relay *D*. ***BB*5** operates the *CO* relay which besides shunting the supervisory lamp at ***CC*1** also switches the cord circuit as for an effective call and so releases the position circuit for other calls.

S.F.J. Cord Circuit. A complete cord circuit for use with S.F.J. junctions is given in Fig. 505. Apart from the special details already mentioned, the cord circuit is very similar to the order-wire junction circuit (Fig. 494). It is, however, interesting to note that in addition to the normal facilities, the circuit is designed for dealing with "follow-on" calls, i.e. the second seizure of a junction before the first call has been cleared down at the B-position. If the plug is removed from the outgoing junction jack before the connexion is taken down at the B-position, relay *S* operates via *LL*2 to the earth on the bush of the multiple jack. ***S*1** operates *SS* and at ***SS*1** and ***SS*2** the junction is isolated from the called subscriber's line. The resistance of *S* (12 000 Ω) is sufficiently high to remove the engaged condition from the multiple. The cord circuit supervisory lamp glows from the earth at ***S*1** via *LL*3 and ***SS*3** until the connexion is taken down. If a second call is received before the first call is completely cleared, relays *L* and *LL* operate, the junction circuit is associated with the position circuit, and the supervisory lamp now flashes to indicate that the cord circuit is associated with the operator's telephone. The telephonist must now take down the previous connexion and so release relays *S* and *SS* before she can establish the second call.

Position Circuit. The complete position circuit is given in Fig. 506. On receipt of a calling signal, one of the uniselectors (depending on whether *SC* or *SD* is energized) hunts and switches to the cord circuit thereby operating *K* or *KK*. The operation of *KK* when the calling junction appears on the banks of the second uniselector, controls the

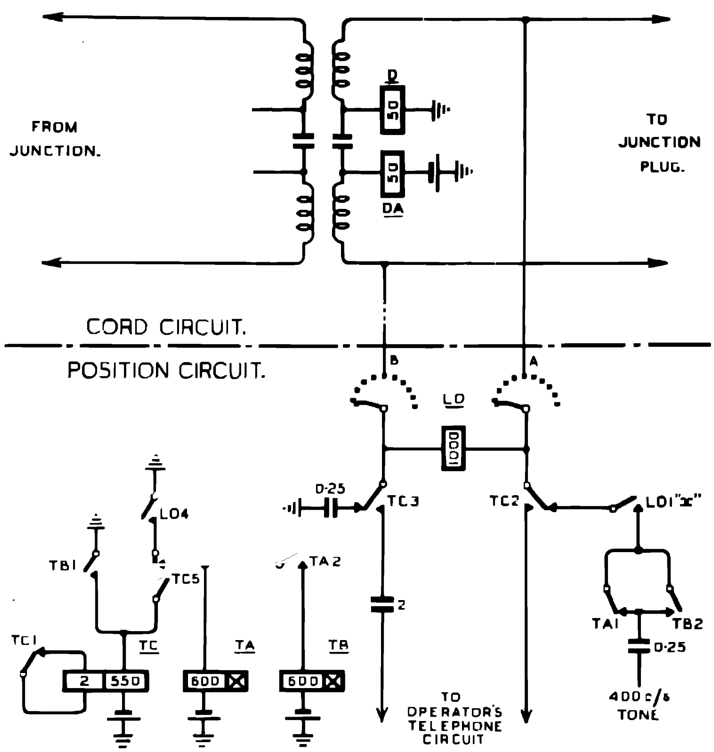


FIG. 503. RETURN OF "PIP-PIP" TONE

switching relay *SW* which in turn switches over the various position circuit leads. As in order-wire junction working, the operator's tertiary circuit is commoned to the tips of all free plugs and, when the engaged condition is encountered, battery potential on the bush of the jack operates relay *TY*. ***TY*1** completes the circuit of the 200 Ω winding of the tertiary transformer via the 0·5 μF condenser to battery. The resultant charging current of the condenser induces an e.m.f. in the receiver circuit to give the usual click indication. The 20 000 Ω leak across the condenser allows the latter to discharge during intervals between testing.

An interesting feature is the provision of an Emergency Jack connected to the operator's telephone circuit. If, for any reason, the cord circuit finders should fail, the B-operator can associate her telephone with any calling junction

by inserting the junction plug into the emergency jack.

Discrimination. The load of each S.F.J. B-position operator is assessed on the assumption that the operator is called upon merely to test and then connect to a line appearing in the multiple.

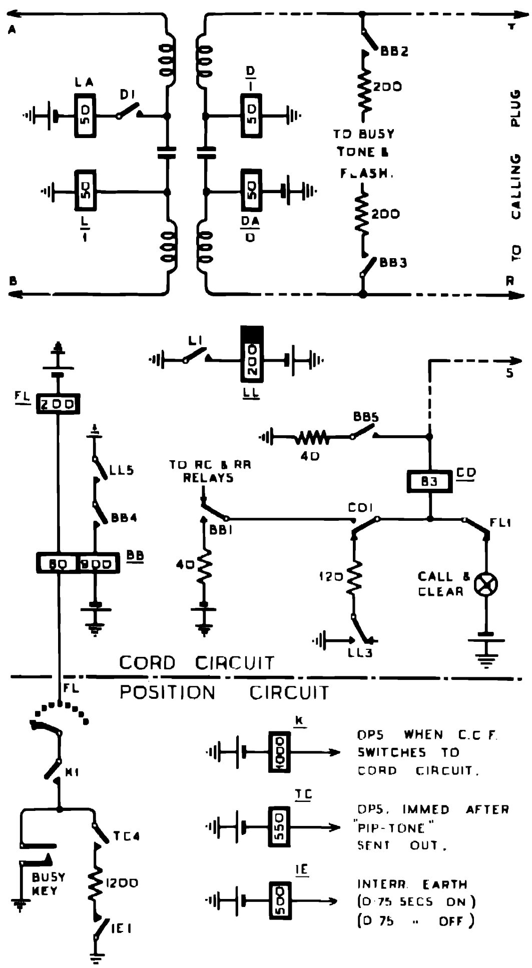


FIG. 504. LAMP FLASH AND BUSY CIRCUITS

In certain areas it is necessary for the incoming operator to dial the number of a subscriber on adjacent automatic exchanges. To place the onus of dialling on the normal S.F.J. operator would seriously degrade the efficiency of the system, and hence it is usual in such circumstances to route to separate positions all traffic of a special nature which requires prolonged attention at the incoming termination. This feature is known as *discrimination* and is illustrated in Fig. 507. At the outgoing exchange, the normal multiple is duplicated and a cross is inserted in the *A*- and *B*-wires of the second appearance. Thus, if a calling plug is inserted into the normal jack, calling battery is sent out over the *B*-wire, whilst if the plug is inserted in the other jack, battery is sent out on the *A*-wire. At the incoming end, the circuit is so arranged that receipt of a battery on the *B*-wire takes up a normal plug-ended S.F.J. cord circuit and the alternative condition lights a calling lamp on the special J.E.J. or similar position.

Six-Position Coupling. The simple straightforward junction working so far described has, in common with the earlier order-wire system, the inflexibility inherent in a system where each junction is terminated on a specific cord. Under conditions of light traffic some form of concentration is required. One solution is to divide the junctions of each incoming route amongst all the available positions so that each position handles traffic from several junctions of each route. This distribution is, in fact, usual, and apart from concentration reasons it provides a ready method of evenly loading the positions. During slack periods, arrangements could be made with the originating exchanges to use only the junctions terminating on certain specified positions. This scheme is, however, very cumbersome and presents practical difficulties on small junction groups and particularly where the traffic varies considerably minute by minute. An automatic system of coupling is therefore employed. A series of relays, operated by the insertion of a telephonist's instrument plug into the position jack, control one or more *coupling uniselectors*. The uniselectors have outlets to the various cord circuit finders and are so arranged that as a position is unstaffed the cord circuits of that position are automatically switched to predetermined adjacent positions. The most usual arrangement is a coupling unit of six positions, and the facilities offered by six-position coupling are indicated in Fig. 508. It should be noted that, for circuit reasons, as the traffic decreases the positions must be de-staffed in a certain definite order. If, for example, in a given suite of six positions (known as A, B, C, D, E, and F), the traffic falls to a minimum such that only three operators are required, these operators must be allocated to positions A, C, and F.

The circuit arrangements of six-position coupling are somewhat complex and cannot be considered here in detail. Fig. 509, however, shows the main features of the switching arrangements. The various contacts are controlled by the insertion of the operator's instrument plugs into the position jacks, e.g. contacts *B* are operated when the operator's instrument plug is inserted in position B and so on.

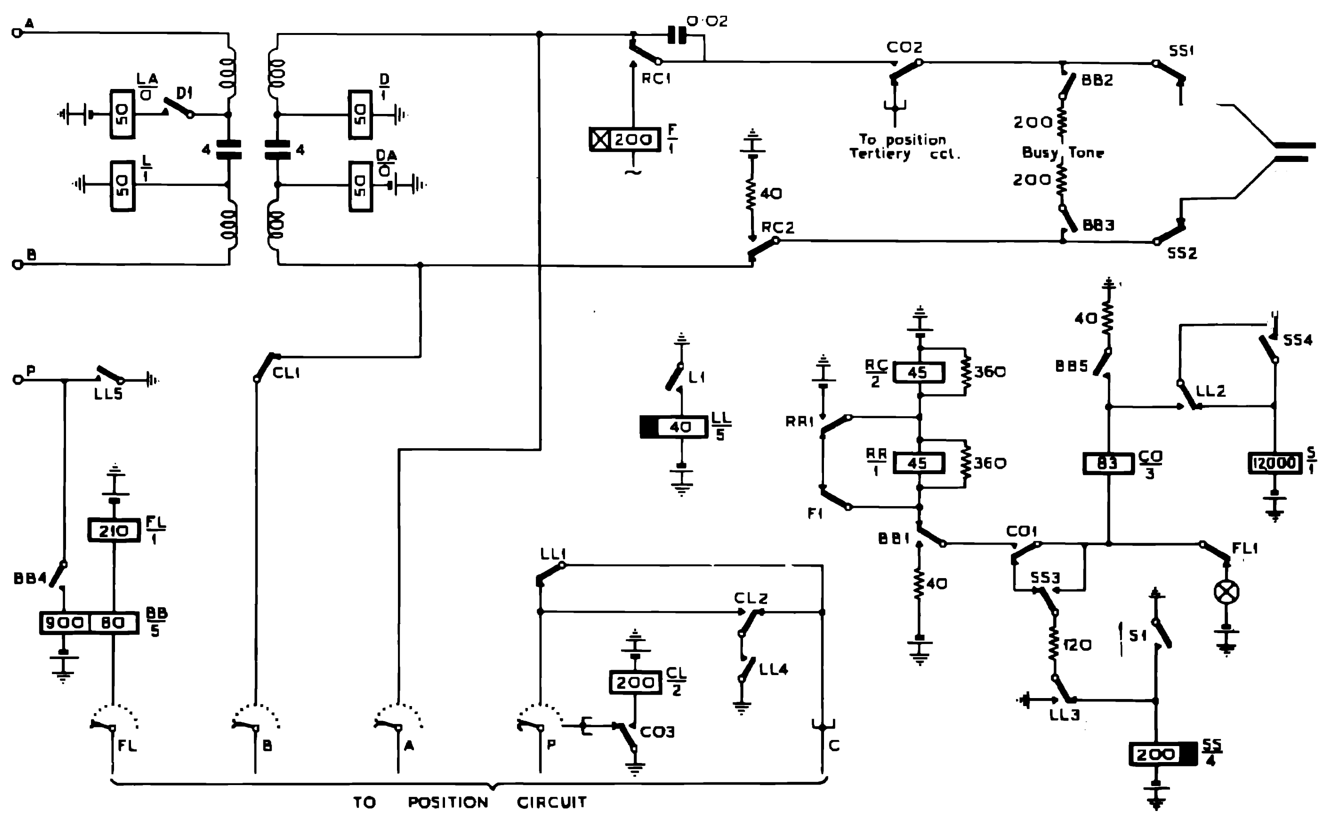


Fig. 505. S.F.J. Cord Circuit

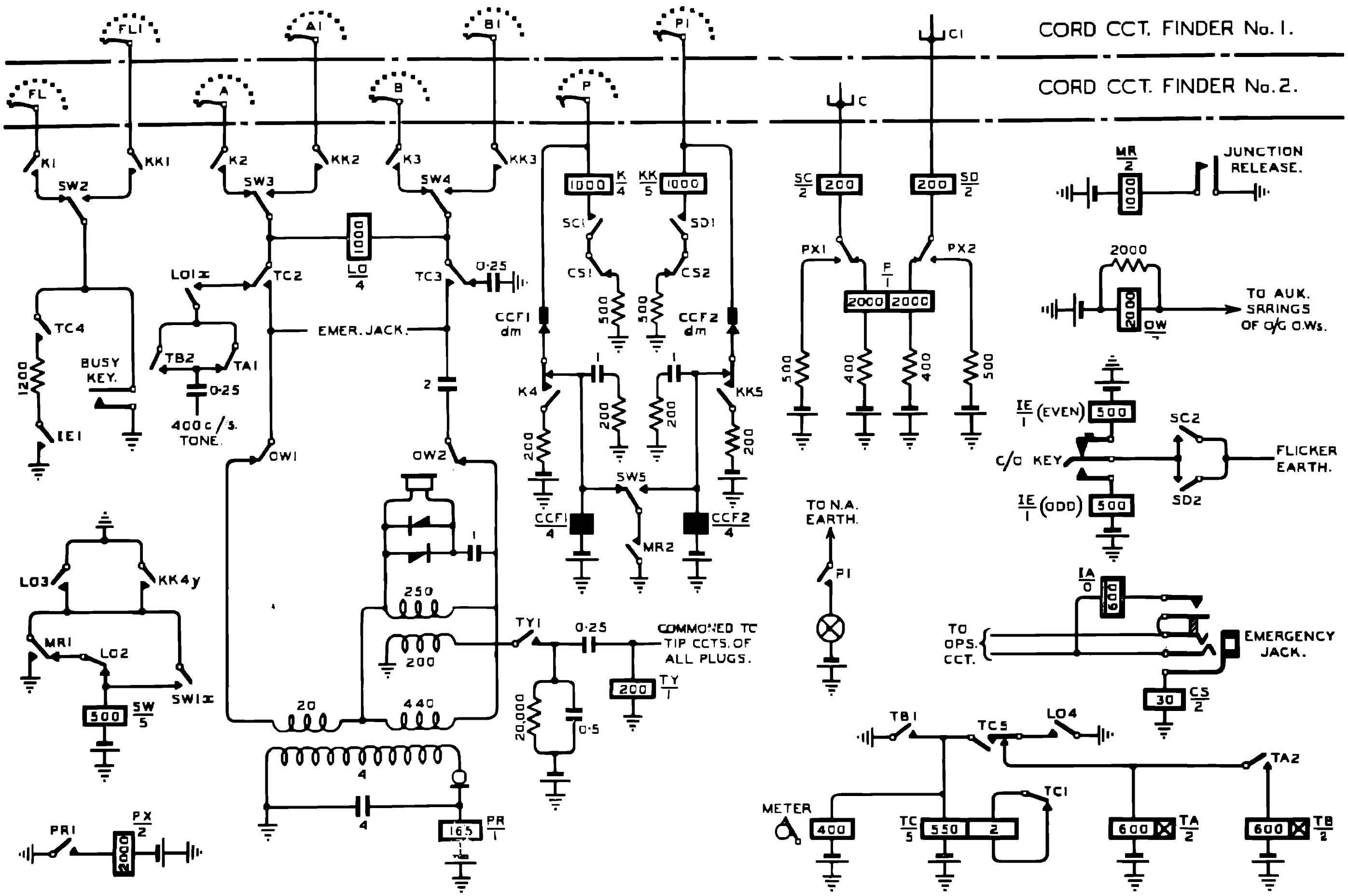


Fig. 566. S.F.J. Position Circuit

A coupling uniselector (*CA*, *CB*, etc.) is provided per position with the exception of position C which requires two uniselectors (*CCA* and *CCB*). When all positions of the coupled group are staffed, each operator is connected direct to the two cord circuit finders of her position. As the traffic falls, position B is unstaffed. Contacts *B* now release and the A and C position operators each take over half of the cord circuits of position B via the coupling uniselectors *CA* and *CCA* respectively. As the traffic further decreases, position E is unstaffed and the cord circuits of this position are taken over by positions D and F through the coupling uniselectors *CD* and *CF*. When the traffic can justify three operators only, positions A, C, and F are staffed. Release of relay *D* now rearranges the loads so that position A takes over the whole of B's cord circuits, position C takes over the whole of position D and position F takes over position E. With two operators, positions B and E are staffed and each operator handles all traffic on her own and both adjacent positions (via coupling uniselectors *CB* and *CE* respectively). Finally, when the staff is reduced to one, position C is used and the operator obtains access to all cord circuits of the full six-position group via coupling uniselector *CCB*.

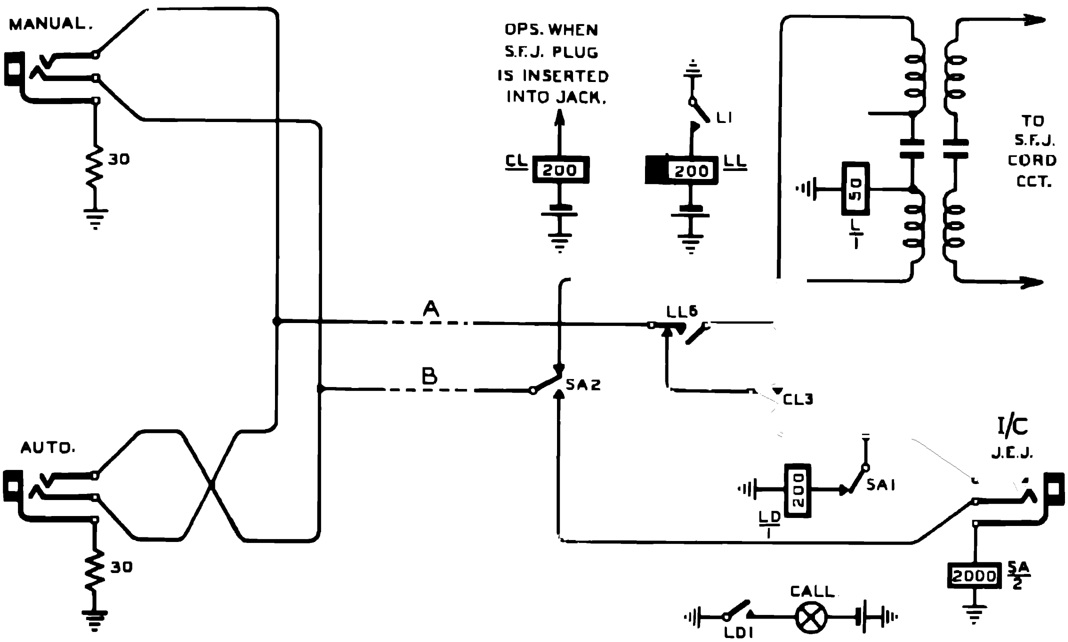


FIG. 507. DISCRIMINATION ON S.F.J. ROUTES

Distribution. Although the operators' loads can be levelled out to some extent by distributing the incoming junctions over all available positions, the loading is, nevertheless, not entirely satisfactory at large exchanges with an appreciable number of B-positions. In such cases an automatic system of distributing traffic to the operators is employed and is illustrated in block form in Fig. 510.

Assume, for example, that the total number of

No. OF OPERATORS STAFFING A COUPLING SUITE OF 6 POSITIONS.	POSITIONS TO BE STAFFED (INDICATED BY X.)					
	POSITION A	POSITION B	POSITION C	POSITION D	POSITION E	POSITION F
6	X	X	X	X	X	X
5	X	X	X	X		X
OR	X		X	X	X	X
4	X		X	X		X
3	X		X			X
2		X			X	
1			X			

FIG. 508. FACILITIES PROVIDED BY SIX-POSITION COUPLING

incoming S.F.J. circuits is 600. Due to the different times of peak traffic on the various routes, it is probable that the maximum number of simultaneous calls will not exceed say, 540. It is apparent therefore that with full availability between the

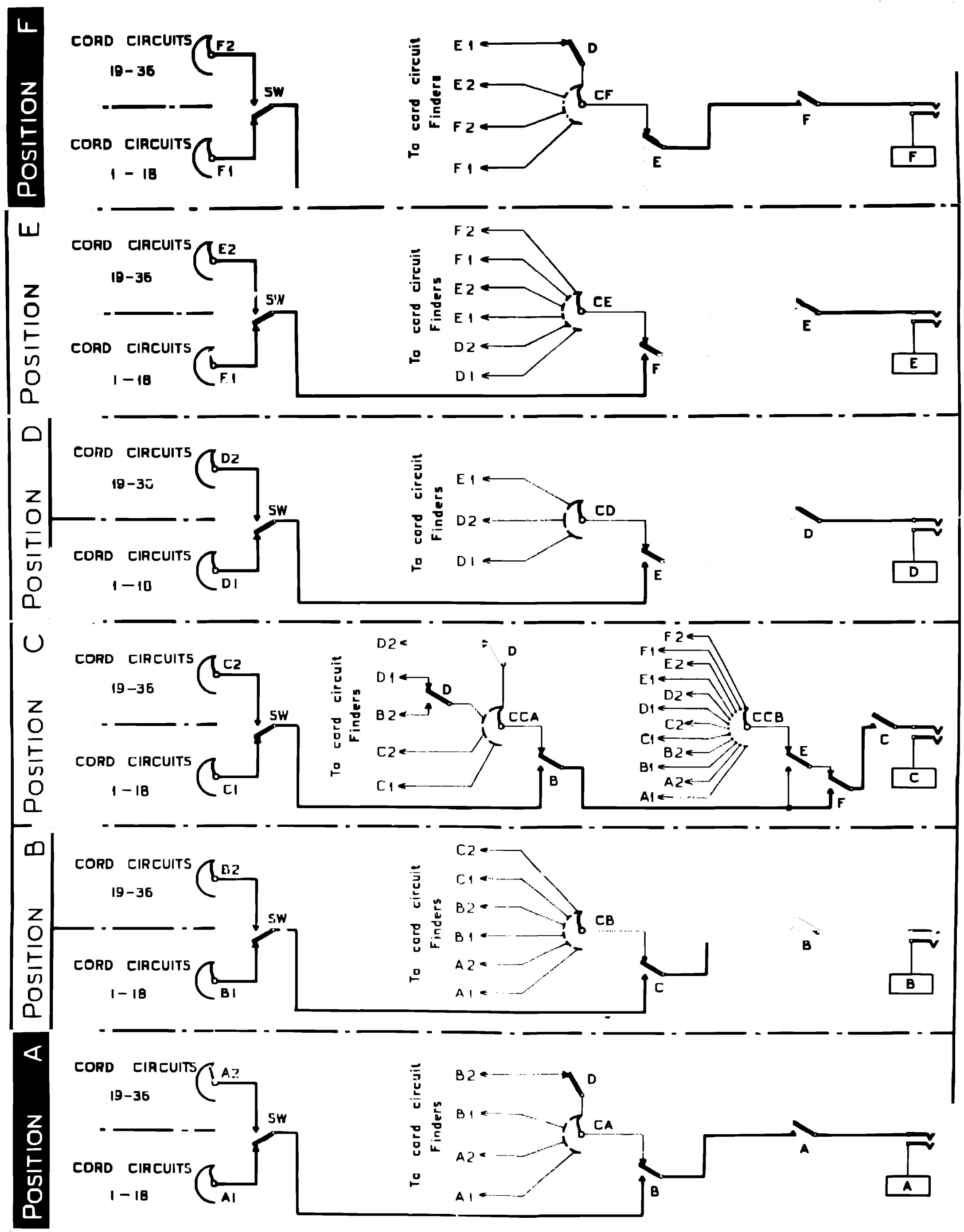


Fig. 509. General Arrangements of Six-position Coupling

positions and junctions, the total number of cord circuits required is 540, which involves the provision of 540/36 = 15 positions. To give this full availability it would require a 600-outlet finder switch in order to couple any junction with any given cord circuit. Such mechanisms are not readily available and in any case the provision of a 600-outlet switch per cord circuit is economically impracticable. A fair approach to full availability conditions is obtained by dividing the whole of the incoming junctions into groups of fifty circuits, each group containing a proportion of the junctions on each incoming route. (Actually in practice the number of circuits per group is limited to forty-nine.) In the example given there will be 600/50 = 12 groups. It is necessary that each operator should have access to each group and hence the thirty-six cords on each position are allocated evenly to all groups. With twelve such groups three cord circuits per position will therefore serve each group. Every cord circuit has a 50-outlet linefinder switch associated with it, and the fifty circuits of the group are multiplied on the banks of the linefinders serving that group. It is apparent, therefore, that each group of fifty circuits will be served by 3 × 15 = 45 linefinders which in turn are connected to three cords on each of the fifteen positions.

In order to distribute the incoming traffic evenly amongst the operators, a cord circuit distributor is provided per group. This distributor determines which linefinder shall search for each call and is arranged to route successive calls to the unoccupied operators in strict rotation. If an operator is engaged with a call, then the cord circuit distributor routes no further traffic to that position until the operator becomes free. If, however, all the available operators are engaged, calls are routed to the positions in cyclic order to await the attention of the operators as they become free.

Linefinder and Distributor Circuits. The calling battery on the B-wire of the junction operates relay *LM* in the incoming line circuit (Fig. 511). ***LM*1** removes the earth from the *P* arc of the linefinders and substitutes the *FC* relay. ***LM*2** operates *LC* which at ***LC*1** sends an earth on the start wire to the distributor circuit.

The earth on the start wire energizes relay *P* in the distributor circuit and at ***P*2** the circuit of the driving magnet is extended to the wipers of the *A* and *B* arcs of the switch. The distributor switch may be standing on any contacts, and if the linefinder connected to these contacts is engaged or if the position to which that linefinder is connected is either busy or unstaffed, there is an engaging earth on the *A*-bank. The distributor driving magnet rotates under the action of its own interrupter contacts so long as the *A*-wiper encounters earth conditions on the bank contacts (wiper *A* is of the "bridging" type to prevent interruption

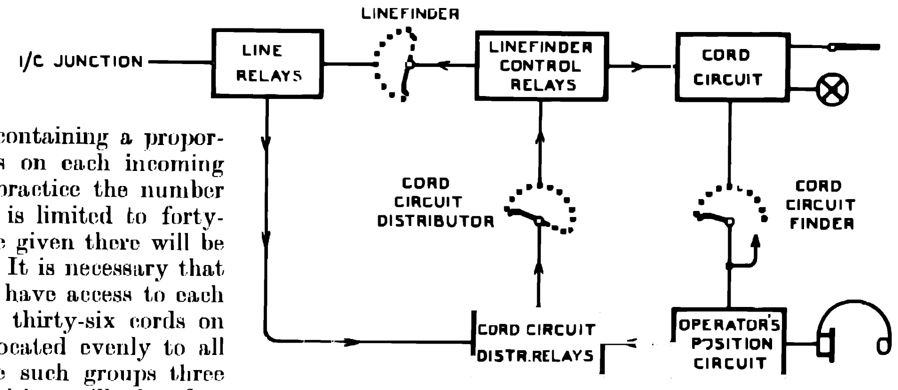


FIG. 510. S.F.J. SYSTEM WITH DISTRIBUTION

of the earth as the wiper passes from contact to contact). When a free outlet is found, the battery at the driving magnet is extended over the *B*-arc to the *LO* relay in the selected linefinder. *LO* operates, but the current is too small to step the driving magnet. ***LO*1** applies the linefinder magnet to the *P*-wiper of the linefinder switch, whilst ***LO*2** applies earth to the *K*-relay. Ordinarily, the *P* contacts of idle junctions are earthed via ***LM*1** and *FC*2, whilst engaged junctions are earthed from the ***K*2** contact of the linefinder in use. The calling junction is therefore the only one with a battery potential on the *P*-contact, and the linefinder switch rotates over the idle or engaged contacts under self-drive in a manner exactly similar to the hunting of the distributor. During the search for the calling junction, the *K*-relay is short-circuited by the earth on the *P*-wiper and that applied at ***LO*2**. When the appropriate contact is reached, there is no further drive circuit for the magnet, and the absence of the *P*-wire earth allows *K* to operate from the *DM* battery to the earth at ***LO*2**. ***K*3** earths the *A*-bank of the distributor and causes the latter to step on. ***K*4** and ***K*5** switch the speaking pair through to the cord circuit, and ***K*2** applies a full earth to the *P*-wire to operate *FC* in the line circuit. ***FC*1** removes the *LM* relay from the *B*-line, ***FC*5** holds *LC*, ***FC*3** disconnects the earth on the start wire, and ***FC*4** provides a holding circuit for the *FC* relay. Relay

P releases and the distributor is free for use on another call.

A relay (*C*) is provided for each junction group on every position. In the hypothetical example there would be twelve such *C* relays in parallel and arranged under the control of relays *SC*, *SD*, *PX*, and *NZ* in the position circuit. *PX* operates whenever there is an instrument plug in the position jack, *SC* or *SD* operate during the time when an operator is dealing with a call (see Fig. (506 and

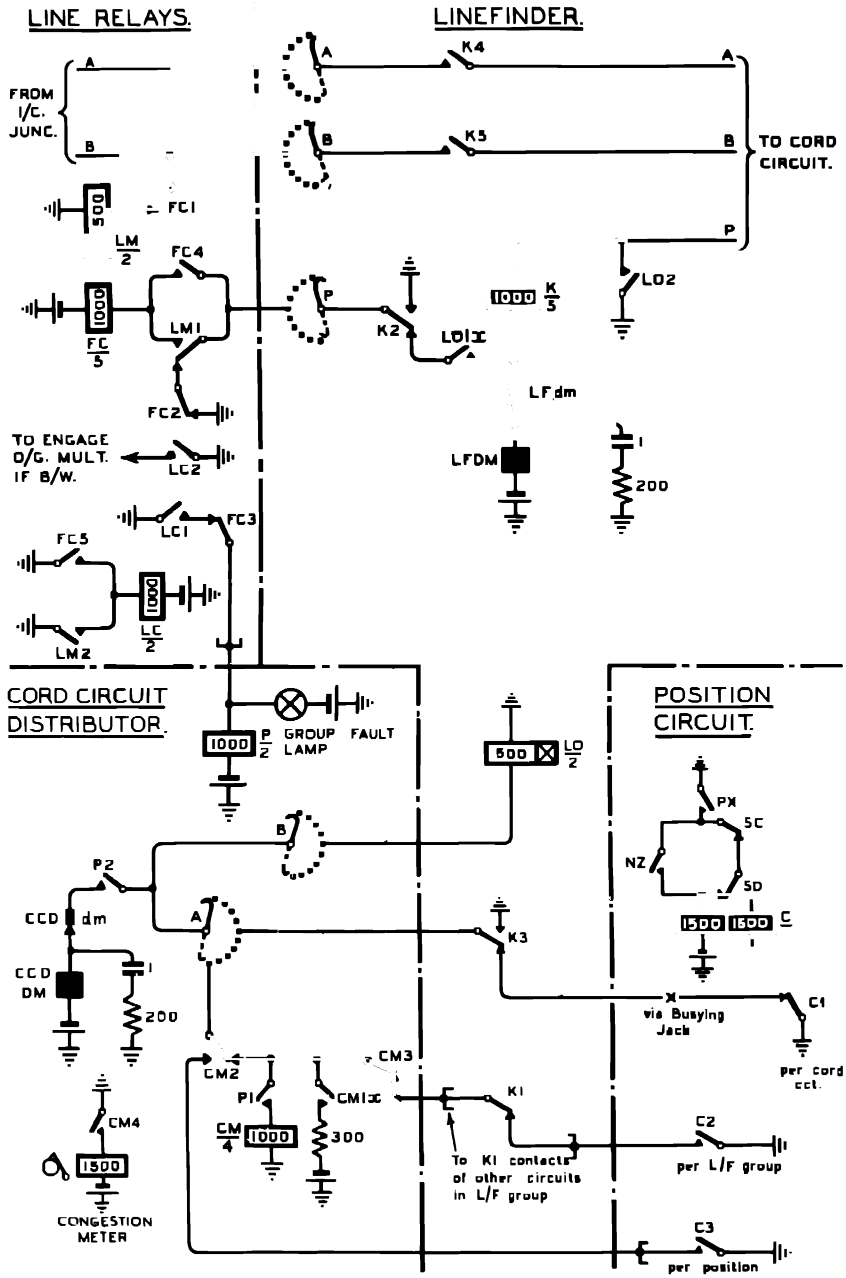


FIG. 511. LINEFINDER AND DISTRIBUTOR CIRCUITS

NZ is a relay operated when all positions are busy. Thus the *C*-relays are energized whenever a position is staffed, and the operator is not engaged with another call, or even when an operator is busy if all other operators are similarly engaged.

A busying jack is provided for each cord circuit on a position in order that any faulty circuit can be busied on the banks of the distributor. From Fig. 511 it is apparent that any particular contact of the *A*-arc is busied either by the engaging of the associated linefinder (***K*3** operated), by the insertion of a busying plug in the jack, or by the release of the *C* relay.

If, now, the cord circuit distributor fails to find an outlet during its search over arc *A*, the wipers are stepped to the last contact. If any one position is able to receive a call, the *C*-relay of that position is operated (***C*2** operated). If there is one cord circuit free (*K*1 normal), an earth is applied to the last contact of the *A*-arc and the distributor continues its search for the free outlet. If, however, the available idle positions have no remaining cord circuits (in the appropriate group) there is no earth on the *K*1—*C*2 common, and relay *CM* operates from the *DM* battery via ***P*1** and locks at ***CM*1** to the 300 Ω resistor. ***CM*3** isolates the *K*1 common whilst ***CM*2** prepares a circuit to step the distributor from the last contact (to continue hunting for a free cord circuit) when one of the positions becomes free. ***CM*4** operates a meter to record the congestion.

Position Opening Distributor. It has already been stated that the distribution arrangements do not give full availability to all junctions. It is therefore possible for all cord circuits of one group to be engaged on one position whilst there are other cord circuits (connected to other groups) free on the same position. For this reason, it is usual to compensate for the loss of availability by the provision of automatically controlled six-position coupling. In Fig. 511 it is shown that any position is closed for incoming traffic by the release of relay *C*. There is a second coil of relay *C*, and a position opening uniselector is provided forcibly to reoperate the *C* relays of selected positions when congestion occurs. The simplified circuit arrangements are indicated in Fig. 512. If the cord circuit distributor cannot find a free linefinder of a staffed and disengaged position, relay *CM* operates as already described. (Fig. 511). Two additional contacts of relay *CM* are provided when a position opening distributor is fitted. Contact ***CM*6** connects either flicker earth or interrupted earth to the stepping relay (*FE*) of the position opening distributor (Fig. 512). If the A position only is staffed, interrupted earth is connected to the *FE* relay. If, however, position B or C is staffed but relay *A* is not, then flicker earth is connected to the *FE* relay to drive the position opening distributor round at a greater speed. There are, therefore, two speeds of forcibly opening positions—the slower speed for use when three or more positions of a coupled suite are staffed, and the faster speed

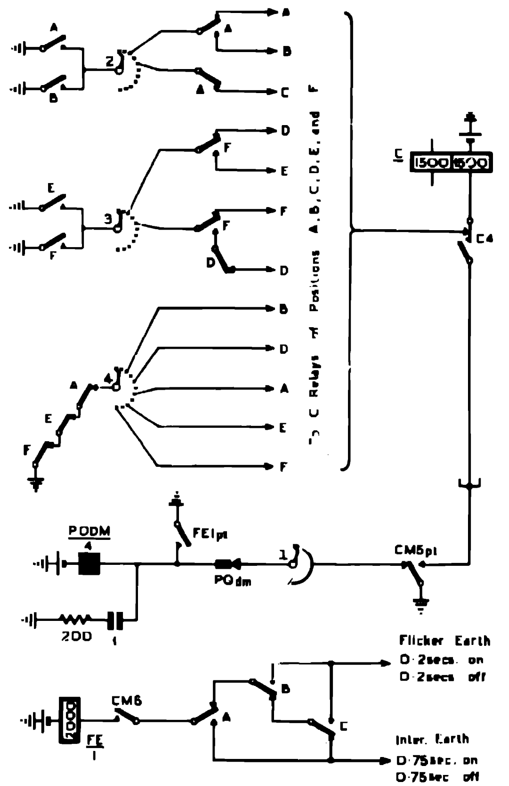


FIG. 512. POSITION OPENING DISTRIBUTOR

when only one or two positions are staffed (see Fig. 508).

Contact ***FE*1** steps the position opening driving magnet at flicker or interrupted earth speed, and arcs 2, 3, and 4 of the position opening distributor apply earth as required to operate the *C* relays of engaged or unstaffed positions. Assume, for example, that three positions only of the coupling group of six positions are staffed. In accordance with the destaffing arrangements these three operators must occupy positions A, C, and F. If now, each of these three positions is closed to traffic due either to the absence of free linefinders in the particular group concerned, or to being engaged on the establishment of other calls, relay *CM* operates and connects interrupted earth to the

FE relay. *FE*1 steps the position opening driving magnet and, after two steps, earth is applied via contact *A*, arc 2, to operate the *C* relay of position B. This enables incoming calls to reach position B where they can be completed by the operators on either positions A or C. In effect, the position opening distributor has opened up to the A and C position operators the cord circuits of position B which are associated with the group in which congestion is occurring. If the opening up of position B relieves the congestion, relay *CM* releases and the drive circuit of the position opening distributor is cut at contact *CM*6. At the same time a homing circuit is provided by the release of *CM*5. It will be noted that *CM*5 in addition to homing the position opening distributor also removes the earth from the holding circuit of relay *C* on any forcibly opened positions so that they are automatically reclosed to traffic as soon as the congestion disappears. If, on the other hand, the opening up of position B does not relieve the congestion, the position opening distributor steps a further two contacts when the *C*-relay of position D is operated via arc 3 of the distributor.

Under full concentration conditions when position C only is staffed the presence of congestion opens at increased speed positions B, D, A, E, and F via arc 4.

Calls from Automatic Exchanges. Calls from automatic exchanges to subscribers on a C.B. exchange can be classified into the two main categories:

(*a*) Calls which can be metered automatically against the automatic subscriber, i.e. if the C.B. exchange is within the automatic metering area of the originating exchange.

(*b*) Calls which are outside the multi-fee area and which must be passed via the automanual operator for ticketing purposes.

The circuits provided for (*b*) can be of any of the types already considered for use between two manual exchanges. The circuit arrangements at the automanual end are of course different, but the method of signalling on the junctions and the terminal circuits at the C.B. exchange can be the same irrespective of whether the call emanates from a distant C.B. or from an automanual exchange.

Junctions carrying traffic dialled by automatic subscribers may in some cases be exclusively used for this purpose. In other circumstances it may be desirable on economic grounds for the junctions not only to carry traffic from automatic subscribers, but also from the automanual exchange operator or even other exchange operators who will obtain access to the junction route via selector levels at the automatic exchange. Moreover the C.B. exchange may or may not be the parent exchange for the automatic subscribers. These considerations require different facilities and hence determine the type of circuit to be provided at the C.B. exchange. Although the facilities are different all circuits, by virtue of the comparatively short distances involved, employ d.c. signalling principles.

Jack-ended Junctions from Automatic Subscribers. Fig. 513 gives a circuit suitable for terminating junctions at a C.B. exchange for traffic dialled out by automatic exchange subscribers. It is similar to the ordinary jack-ended C.B. signalling junction but is, in addition, arranged to receive a second call from the automatic exchange if the previous call has not been taken down by the incoming C.B. exchange operator. This facility is particularly desirable on calls from an automatic exchange on account of the much more rapid release of the selectors at the outgoing end as compared with the normal time taken for a B operator to clear down.

When the circuit is seized from the selector level at the automatic exchange, battery on the *B*-wire operates *L* to the earth at *T*2. ***L*1** operates *B* and ***B*2** in turn lights the calling lamp, whilst ***B*4** returns ringing tone to the calling subscriber. When the operator answers, relay *S* is energized and at ***S*1** the circuit of the calling lamp is disconnected. ***S*3** engages the outgoing junction multiple if the circuit is used as a bothway junction, and ***S*2** disconnects ringing tone. The earth returned on the tip circuit from the answering cord operates relay *T* via *T*1 and ***B*3**. ***T*2** switches the *B*-line through for conversation, the *L*-relay now being held to the earth in the cord circuit. ***T*1** locks the *T* relay under the control of ***B*3**. At the end of the conversation the automatic subscriber normally releases first and the release of *L* disconnects *B*, which at *B*1 completes a circuit for the *CO* relay to the earth at ***S*4**. *CO* locks under the control of *S* via its contact ***CO*3**. ***CO*1** and ***CO*2** disconnect the speaking pair from the cord circuit. If the incoming C.B. exchange operator takes down the connexion before a second call is received on the junction, relay *S* releases and restores the whole circuit to normal. If, however, a second incoming call arrives before the plug is withdrawn, the re-operation of *L* and *B* relights the calling lamp from the earth at ***S*4** via ***CO*3**, ***B*1**, and ***S*1**. ***B*4** re-applies ringing tone to the calling subscriber. The attention of the operator is thus drawn to the second call which is completed in the normal manner.

This circuit can also be used on junctions which carry joint traffic from automatic subscribers and

from distant manual exchanges. Although the circuit was designed primarily for dialled calls it can, in fact, be used to advantage wherever the normal jack-ended junction (Fig. 489) is required. If, however, any incoming route is accessible to automatic subscribers on a dialling basis it becomes necessary to prevent "key-supervision" on that route. In the normal jack-ended B-position cord circuit, battery is returned on the *A*-wire when the operator answers and also when the called subscriber replies. It is therefore necessary to disconnect the speak key contacts (*SK*3 in Fig. 490) of all cord circuits on any B-position handling traffic from auto subscribers. Although this expedient avoids the possibility of premature registration it does, unfortunately, prevent key supervision being given on *any* incoming junctions answered by that operator. Key supervision on routes from manual exchanges is very desirable and, if the amount of such traffic is large as compared with that from the automatic subscribers, it is preferable to install modified incoming circuits for the latter rather than to delete key supervision on all cord circuits of the position. When key supervision is retained, the modifications to the incoming circuit are shown by the broken lines in Fig. 513. Instead of the supervisory (and metering) condition being returned directly to the automatic exchange, the receipt of battery on the ring conductor from the cord circuit now operates *D*, which at ***D*1** lights a meter lamp. The operator ignores glows due to the throwing of her speak key, but when the lamp glows after the connexion has been established (i.e. when the called subscriber answers), the operator depresses the plunger type meter key associated with the incoming junction jack. Operation of this key energizes *M*, which at ***M*1** locks for the duration of the call and at ***M*2** extends the supervisory battery back over the *A*-wire of the junction. Even with this modified circuit, it is not possible for obvious reasons to give key supervision on joint access routes except after the operator has ascertained that an incoming call is from a manual operator and has depressed the meter key.

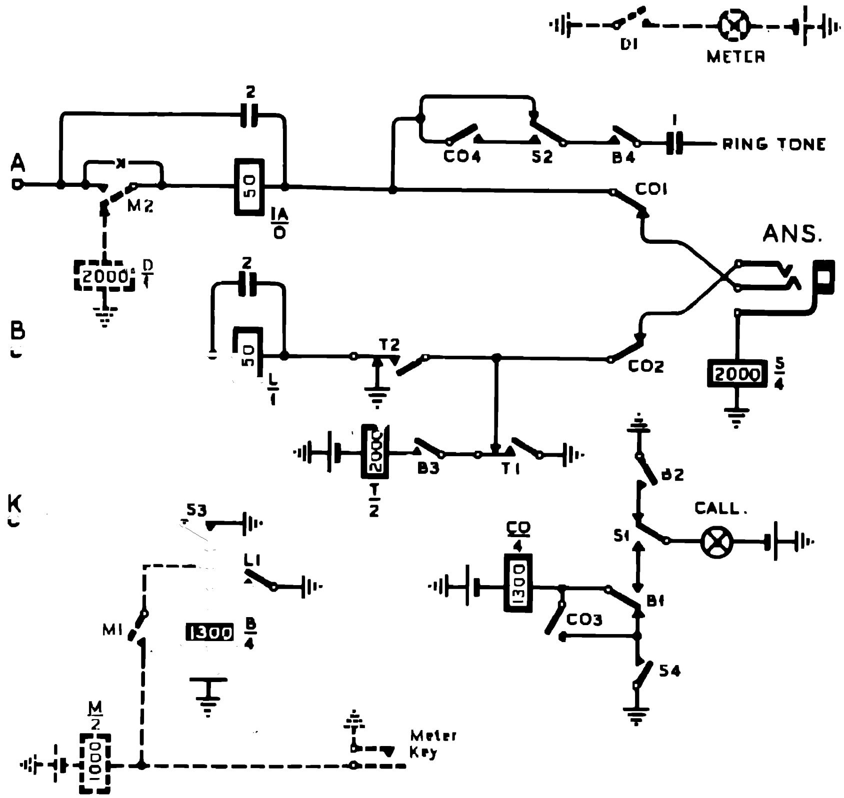


FIG. 513. INCOMING JUNCTION FROM AUTOMATIC EXCHANGE

Assistance Circuit from Remote Automatic Exchange. Sometimes an automatic exchange is parented on a nearby C.B. exchange. In these circumstances automatic subscribers must have access to the C.B. exchange for all trunk and toll calls and for assistance traffic. It is necessary on such circuits that the operator at the parent exchange should know whether a call emanates from a private subscriber at the automatic exchange or from a call-box, and hence the circuit shown in Fig. 514 is often used when a common group of "O" level circuits is provided. Two jacks per incoming junction are required and separate calling lamps indicate whether the call is from a coin-box or an ordinary subscriber. If the call originates from an ordinary subscriber, the junction is looped at the outgoing end and relays *L* and *LC* are energized. ***L*1** operates *LB* whilst ***LC*1** operates

LL. *LB* and *LL* are provided with six and seven sets of contacts respectively, so that up to a maximum of six appearances of the answering jack can be provided to facilitate team working. The operation of *LL* and *LB* together lights the calling lamp associated with the "ordinary" jack and ringing tone is returned to the calling subscriber by *LL7*. When the operator answers, *S* is operated reversal of the line connexions to the answering jacks, this battery is returned to the automatic exchange over the *A*-wire and is utilized at the outgoing end to provide a manual hold facility (see Fig. 384.) Metering is not provided on this circuit.

Dialling to Automatic Exchanges. Calls from a C.B. exchange to subscribers on a nearby automatic system may be completed either over ordinary

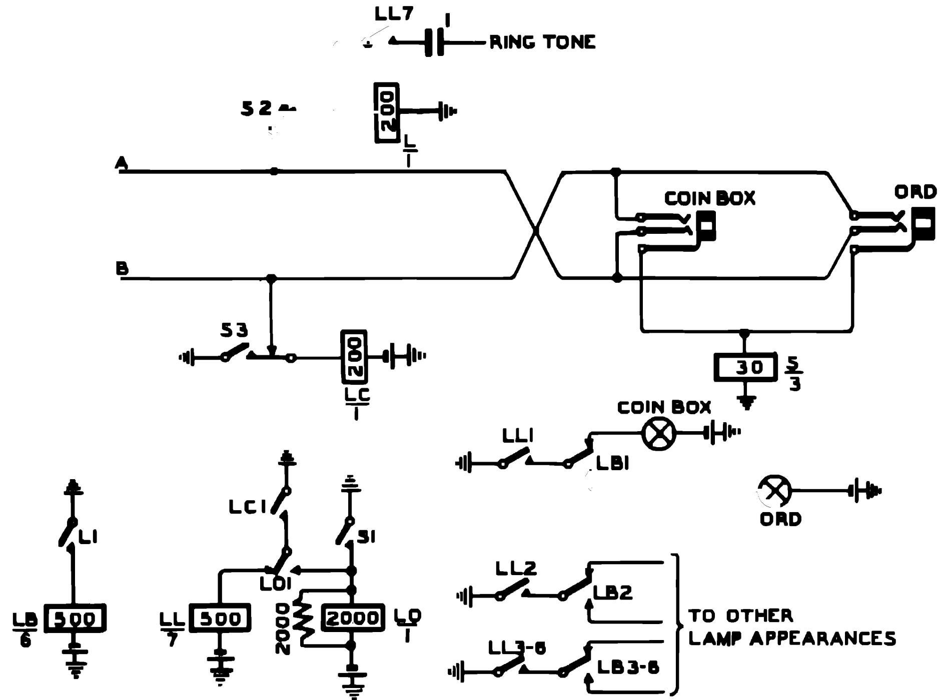


FIG. 514. "O" LEVEL CIRCUIT WITH COIN-BOX DISCRIMINATION

and at *S2* and *S3* the *L* and *LC* relays are removed from the speaking pair. *S1* operates *LO* which locks to *LC1*, the *LC* relay being held by *S3*. The operation of *LO* releases *LL* and so darkens the calling lamps. The circuit is arranged so that, when a call has been answered, the calling lamp is locked out for the duration of the call even if the plug is removed from the junction jack.

If the call emanates from a coin-box subscriber an earthed loop is sent out from the automatic exchange. Relay *LC* operates at the incoming end, but *L* cannot operate due to the presence of the earth. *LC* operates *LL* as before and, *LB* being normal, the calling signal is applied to the coin-box lamp. It will be noted that the sleeve relay is of 30 Ω resistance like an ordinary subscriber's line, and hence the jack-ended B-position cord circuit returns battery over the ring conductor immediately a call is answered. Due to the signal junctions to the automanual exchange or by direct dialling from the C.B. exchange. The arrangements necessary on A-positions at a C.B. exchange to provide dialling are shown in Fig. 515. In addition to the dial which is mounted on the keyshelf, a locking type *dial switching key* is provided per-position. The circuit is so arranged that an operator can, by throwing the dial switching key and by holding the speak and ring key in the ringing position, connect her dial to an outgoing junction. Auxiliary springs of the dial switching key light a dial guard lamp to draw attention to the fact that the ringing supply to the cord circuits of the position is cut off. Either loop or battery dialling may be employed depending largely upon the junction resistance limits. The 2 μF condenser and 40 Ω resistance in the dial circuit act as a spark quench and avoid high induced e.m.f.'s on the line.

Whilst loop dialling is generally preferable to battery dialling, it is not possible to provide loop dialling direct from the cord circuit at 40 V exchanges or at 22 V exchanges if the line resistance exceeds approximately 350 Ω. The difficulty arises due to the conditions which exist after the dial switching key and ringing key have been restored to normal and before the called subscriber answers. Under these pre-answer conditions the automatic selectors at the distant end are held by the difference in voltage of the C.B. and automatic exchange batteries. (See Chapter XIII.)

When the holding conditions prohibit the use of loop dialling, it is possible to introduce an impulse repetition bridge in the outgoing circuit to isolate the cord circuit from the line. By this means, the limits of loop dialling are determined only by the degree of impulse distortion and are independent of the voltage of the C.B. exchange cord circuit. A typical circuit is given in the following pages, but, in general, since a fairly complex outgoing relay set is required the scheme is adopted only where there are objections to the employment of battery dialling (e.g. on amplified circuits).

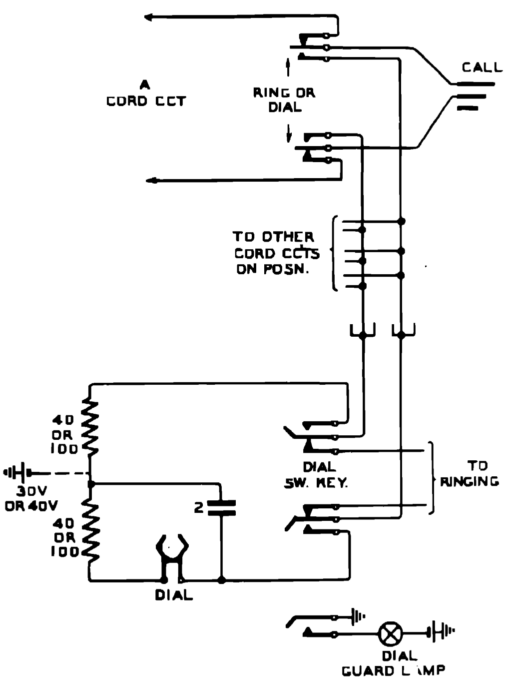


Fig. 515. Dial Switching Circuit

False Impulse Suppression. There is a danger of false impulses being passed to the automatic exchange when loop dialling direct from the cord circuit is employed. If, for example, the ringing key were operated after the insertion of the plug, the automatic selector would be seized by the battery from the cord circuit and a false impulse would be given during the change-over of the ringing key contacts. Similar conditions are produced at the dial switching key contacts and also due to irregular contact as the plug is inserted in the outgoing jack. It is usual therefore to provide false impulse suppression equipment (Fig. 516) on all outgoing loop-dialling junctions. The circuit is arranged so that the selector at the distant end is not seized until the sleeve connexion and the loop from the dial circuit are both established. Relay *L* now operates from the 40 Ω battery and locks to *S1*. *L1* and *L2* complete the line circuit.

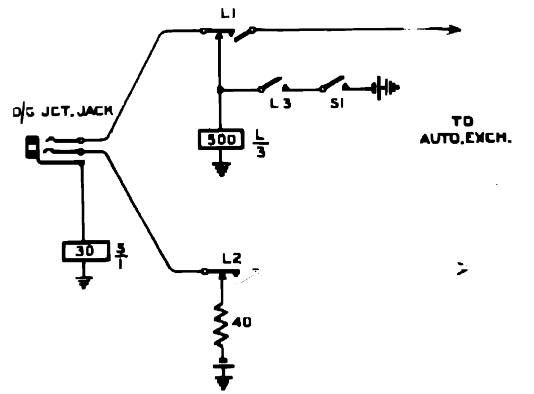


Fig. 516. False Impulse Suppression Circuit

Impulse Conversion Equipment. It sometimes occurs that at a C.B. exchange where a considerable number of junctions are equipped for battery dialling it is necessary to provide loop dialling conditions over a comparatively small number of junctions to a nearby automatic exchange. To obviate the necessity for providing mixed cord circuits on the positions, all the cord circuits are arranged for battery dialling, but conversion equipment is introduced into those junction circuits which require loop dialling conditions. The equipment is in the nature of auxiliary apparatus and receives battery impulses from the cord circuit, converting them to loop impulses in the junction. When the converse conditions apply, i.e. when the majority of junctions require loop dialling and an occasional junction only requires battery dialling, loop-to-battery dialling conversion equipment is employed.

Loop Dialling Circuit for Long Junctions. Fig. 517 shows a circuit recently developed for use on junctions of high loop resistance where hitherto

battery dialling only has been permissible. The circuit is suitable either for two-wire unamplified or four-wire amplified circuits and will give satisfactory loop impulsing on junctions of up to 1500 Ω resistance (loop). The cord circuit battery is completely isolated from the line by the 4 μF condensers, and the impulses are repeated to the junction by relay *A*. There are therefore no restrictions due to the holding conditions after dialling, and hence the circuit can be employed at either 22 V or 40 V exchanges. Relay *A* is so designed that, with both coils in series, there is a minimum of distortion on two-wire junctions of medium length. If it is desired to provide the circuit on long four-wire amplified lines, one coil of *A* is substituted by a 200 Ω resistor and the *LA* relay is similarly treated to maintain the impedance balance. The ampere-turns applied to the *A*-relay are now reduced to one half, and the resulting longer operate lag and the shorter release lag give an artificial distortion which counteracts the impulse distortion introduced by a long four-wire circuit. The 700 Ω resistor and the 4 μF condensers are connected across the position dial circuit during impulsing and the values are chosen to give the most satisfactory impulsing under the various conditions of use.

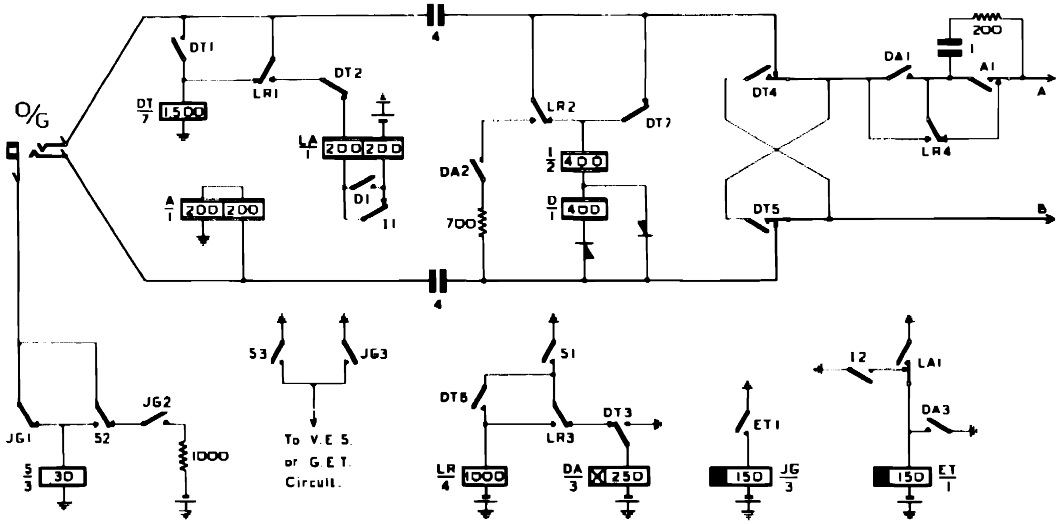


FIG. 517. LOOP DIALLING CIRCUIT FOR LONG JUNCTIONS

Relay *A* operates from the battery on the ring of the cord circuit when the plug is inserted in the outgoing jack. At the same time, *S* is operated over the sleeve conductor and *S*1 energizes *DA*. Contact ***DA*1** seizes the selector at the distant exchange with the loop formed by relays *D* and *I*. It will be noted that *DA* is made slow to operate so that, if *S* flicks during the insertion of the plug *DA* does not operate or, if operated, remains held. ***DA*3** energizes relay *ET* and ***ET*1**, in turn, operates *JG*. ***JG*1** and ***JG*2** prepare a circuit to maintain the engaged condition on the multiple until the circuit fully restores to normal. ***JG*3** similarly maintains the visual engaged signal or group engaged tone.

The operator now throws the dial and ring keys. The position dial circuit is arranged for battery dialling, and relay *DT* operates to the battery over the tip circuit. ***DT*1** provides a holding circuit for *DT* independent of *LR*, ***DT*2** disconnects *LA*, whilst ***DT*3** holds relay *DA*. ***DT*4**, ***DT*5**, and ***DT*7** disconnect the *D* and *I* circuit and complete the impulsing loop. ***DT*6** operates *LR* which holds to ***LR*3**. ***LR*4** removes the short circuit from *A*1 and short-circuits ***DA*1**. ***LR*2** applies the 700 Ω resistor to the impulse accepting circuit.

After dialling, the operator restores the dial and ring keys. Relay *DT* now releases and at *DT*2 connects the supervisory relay *LA* to the tip wire. *DT*4, *DT*5, and *DT*7 disconnect the impulsing loop and restore the *D* and *I* loop. *DT*3 releases relay *DA* which restores after a lag of 100–150 msec. Relay *I* operates to the current in the junction circuit and at ***I*1** disconnects the supervisory battery on the tip wire and so lights the cord circuit supervisory lamp. ***I*2** holds *ET* against the release of *LA*. When the called subscriber answers, the reversal of the line current operates *D* which at ***D*1** reconnects the battery at *LA* to darken the

pervisory lamp. At the end of the call, *D* releases hen the called subscriber clears and at *D*1 again ghts the cord circuit lamp. The operator now takes down the connexion and all relays restore to normal. If the called subscriber is engaged, relay the call is for an automatic exchange, the A-operator selects a disengaged junction and inserts the calling plug into the jack. Battery sent out over the ring of the calling plug causes the equipment at the automatic exchange to hunt for and seize

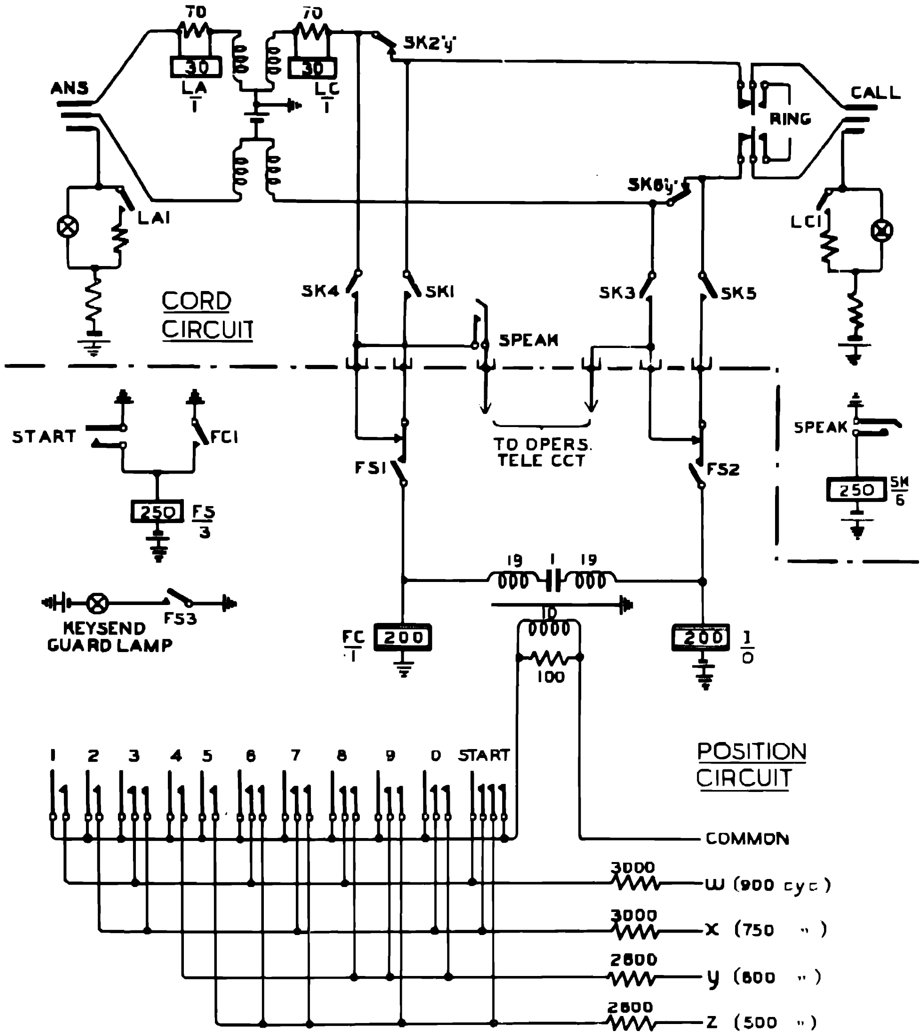


FIG. 518. MODIFICATIONS TO A-POSITION CIRCUITS FOR VOICE-FREQUENCY KEYSENDING

I responds to busy flash conditions and repeats the flash to the supervisory lamp.

Modifications to A-Position Circuits for Voice-frequency Keysending. The modifications required in the cord and telephone circuits of a normal A-position to allow of voice-frequency keysending are shown in Fig. 518. On receipt of a calling signal from a subscriber, the operator ascertains the number required in the usual manner, and if a disengaged sender. When the automatic exchange apparatus is ready to receive the call, battery is returned over the *A*-wire of the junction to operate relay *LC* on the calling side of the cord circuit. ***LC*1** as usual shunts the calling supervisory lamp. A two-"pip" tone of 900 c/s is also returned from the automatic exchange to indicate to the operator that the call may be set up. To key up the call, the operator depresses the start key which completes

the circuit for the operation of relay *FS*. ***FS*3** completes the keysend guard lamp circuit, whilst ***FS*1** and ***FS*2** connect the keysending transformer to the junction. At the same time contacts ***FS*1** and ***FS*2** disconnect the answering cord from the calling cord and remove the operator's telephone circuit from the signalling wires. The circuit for *LC* is thereby disconnected and the calling cord supervisory lamp glows. Relay *FC* and the impedance coil *I* are connected to the tip and ring wires respectively of the calling plug. The start key also connects the *w*, *x*, *z* combination to the junction which sets up cancel conditions to clear any false set up which may have occurred due to the presence of voice frequency currents on the line.

The operator now keys up the required number by depressing in turn the appropriate digit keys, and the frequencies as shown in Fig. 518 are sent out to the junction via the keysender transformer. The resistors in the voice-frequency supply leads to the position are inserted to prevent the mixing of frequencies on any one position due to the simultaneous depression of digit keys on other positions. The depression of the last digit key allows the keysender equipment at the automatic exchange to send out the required impulses to step the automatic switches and, on the completion of impulsing, the sender mechanism automatically disassociates itself from the junction. The battery returned from the automatic exchange on the *A*-wire is now disconnected and relay *FC* releases. *FC*1 disconnects the circuit of relay *FS* whilst *FS*1 *FS*2 and *FS*3 in turn disconnect the keysend lamp and restore the operators telephone circuit to the speaking pair. The restoration of the speak key disconnects the circuit of relay *SK* and the operator's telephone circuit is disconnected from the cord circuit.

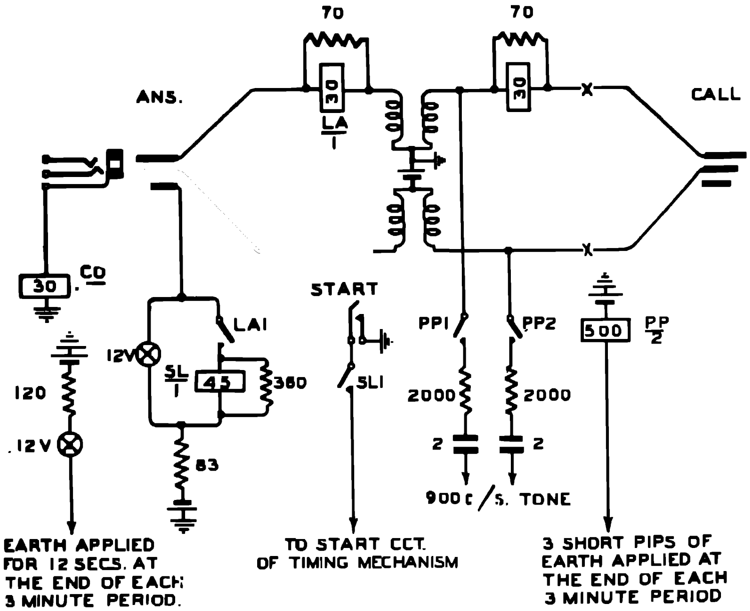


Fig. 519. Control of Call Timing Mechanism

Control of Call Timing Equipment. All trunk calls and all except the shorter junction calls are accurately timed for call charge purposes by means of automatic mechanisms. Details of the timing mechanisms are considered later in Chapter XIX in connexion with sleeve control type exchanges and it is sufficient, for the present, to examine how the timing equipment is applied to C.B. exchange circuits. A number of cord circuits of each A-position, depending upon the volume of timed traffic, are equipped with timing facilities. The circuit arrangements provide for the mechanism to be started by the operator when she has satisfied herself that a call has been satisfactorily established, and for the mechanism to be stopped automatically when the calling subscriber replaces his receiver. Fig. 519 shows the modifications to an A-position cord circuit at a 22 V exchange. The normal 40 Ω resistor in the sleeve circuit of the answering cord (Fig. 472) is replaced by relay *SL* which has a similar resistance. *SL* is controlled by *LA* which in turn is energized by the loop from the calling subscriber.

When a call has been established, the operator throws the start key of the timing equipment and earth is extended via ***SL*1** to the start circuit of the timing mechanism. As the call proceeds, the mechanism is stepped by clock pulses, and just before the end of the third minute, three short pulses of earth are applied to relay *PP*. ***PP*1** and ***PP*2** connect 900 c/s tone to the speaking conductors during each operation of *PP* to give a distinctive "three-pip" time announcing signal to the subscribers. At the same time, an earth is applied to the associated time check lamp for 12 sec to advise the operator of the expiration of the three-minute period so that she can, if necessary, collect additional fees on calls from coin-box lines. The time announcing signal and the 12 sec flash of the

time check lamp are repeated at the end of each succeeding three minute period, but if the call continues to the limit of the timing mechanism (usually 9 or 18 min) the time check lamp flashes continuously to inform the operator that the mechanism requires resetting.

When the calling subscriber replaces his receiver, relay *LA* releases and at *LA*1 disconnects *SL*. *SL*1 now breaks the start circuit of the timing mechanism to prevent further stepping —irrespective of the fact that the start key may not be restored until some time later. It will be noted that the time check lamp is of the 12 V type with a series voltage dropping resistance to obtain uniformity with the 12 V supervisory lamps.

EXERCISES XVII

1. Assuming that a call has been dialled by a subscriber to a jack-ended junction equipment at a central-battery exchange, and that the B-position operator does not withdraw the answering plug from the jack after the connexion has been released at the automatic exchange, show how the attention of the operator is drawn to a second call established over the same junction. How is premature metering prevented when the operator answers a call on such a circuit? Give simple circuit diagrams. (*C. & G. Telephony, Grade II*, 1945.)

2. Draw a circuit diagram of the dial and associated equipment necessary for dialling-in from a central battery cord circuit to an automatic exchange. State the circumstances in which a false impulse is liable to be transmitted and show how it is suppressed by a suitable arrangement of the outgoing junction equipment. (*C. & G. Telephony Grade II*, 1944.)

3. Explain what is meant by "through signalling" on junction lines between central battery manual exchanges. Describe how through signalling is provided in a typical case, giving a diagram of the circuit elements concerned. (*C. & G. Telephony, Grade I*, 1944.)

4. Describe the principal features of the straightforward junction system without distribution. Explain, with the aid of a diagram of the circuit elements concerned, how the "B" position operator's telephone is automatically connected with a junction which has been seized by an A-position operator at the outgoing end. (*C. & G. Telephony, Grade II*, 1943.)

5. Describe, with explanatory circuit diagrams, the main features of the straightforward junction system, including the arrangements employed for distributing traffic over a number of staffed positions. (*C. & G. Telephony, Grade II*, 1942.)

6. Draw a diagram of a typical plug-ended junction circuit at a manual exchange, and explain: (*a*) the functions of the repeating coil, and (*b*) why a key operation is not necessary for ringing the called subscriber. (*C. & G. Telephone Exchange Systems I*, 1947.)

7. Describe a standard system of signalling over jack-ended junctions between central battery manual exchanges. Give diagrams of the line and cord circuit elements concerned. (*C. & G. Telephony, Grade I*, 1940.)

8. What are the merits of straightforward junction working? Describe, with reference to a simple circuit diagram, how a calling junction is extended to a free cord circuit on one of a group of four operator's positions. (*C. & G. Telephony, Grade II*, 1939.)

9. Give diagrams showing the circuit elements required for (*a*) loop dialling and (*b*) battery dialling over junction lines from central battery manual exchanges to automatic exchanges.

State the reasons for providing resistors and a condenser in the dialling circuit at the manual end. Explain how false impulses are suppressed in each of the circuit arrangements.

In what circumstances is it practicable to adopt the loop dialling method? (*C. & G. Telephony, Grade II*, 1940.)

10. Give a diagram of the modifications required to provide voice-frequency keysending from an A-position at a C.B. exchange.

CHAPTER XVIII

THE SLEEVE CONTROL SYSTEM

The principles of the sleeve control system of manual switching have already been considered in Chapter X. Briefly, the main difference between bridge control and sleeve control is that in the former the supervisory lamps are controlled by signalling relays in the cord circuit whereas, in the latter, all signalling relays are in the line terminations and the cord circuit supervisory lamps are controlled via the sleeve connexions of the plugs and jacks. Cord circuits are common to a position and must be capable of connecting together lines employing diverse signalling methods. At trunk exchanges in particular, the lines require many different methods of signalling, and hence complications arise in the design of a bridge control cord circuit to meet all conditions. The sleeve control system is therefore now standard for all trunk exchanges and for automanual switchboards. Apart from signalling requirements, the placing of the transmission bridge in the line termination enables a cord circuit of zero transmission loss to be used. The transmission loss of the terminal equipment can, of course, be made up by the line amplifiers to give a circuit of the required overall transmission efficiency. If necessary a number of lines each of zero loss can, in the sleeve control system, be connected together to give a link with an overall zero loss.

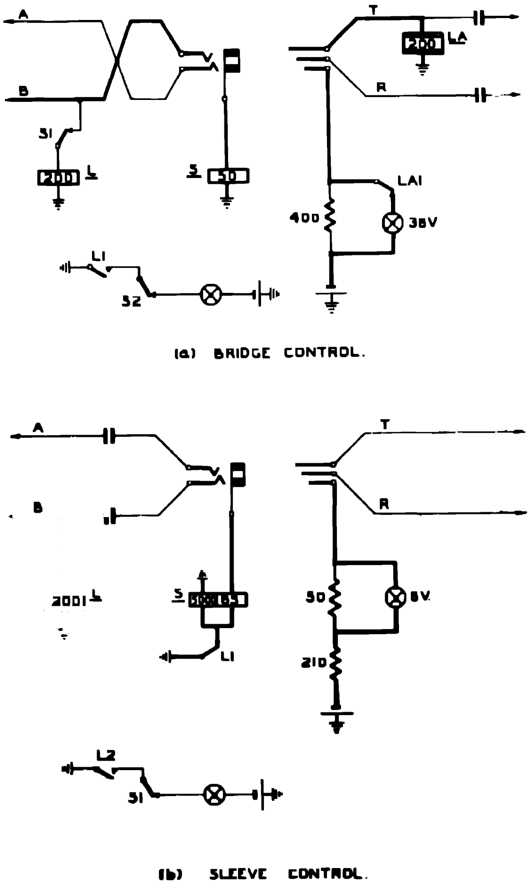


Fig. 520. Control of Cord Circuit Supervisory Lamp

It is, perhaps, desirable at this stage to point out that, in the sleeve control system, although the cord circuit supervisory lamps and certain other operations are controlled over the sleeve circuit, the signalling between connected line terminations takes place over the tip and ring conductors of the cord circuit. In the same way some of the control between the operator's position and the line terminations takes place over the speaking pair.

Control of Cord Circuit Supervisory Lamps. Fig. 520 shows, in principle, the method of controlling the cord circuit supervisory lamp under the bridge control and sleeve control systems. For simplicity, C.B. signalling (calling battery on the *B*-line) is assumed—although the same principles apply with all other methods of signalling. In both systems, the receipt of a calling signal operates relay *L* which in turn lights the calling lamp. When the operator inserts an answering plug into the jack, the sleeve relay *S* operates and disconnects the calling lamp circuit. In the bridge control system the calling signal is extended to operate relay *LA* in the cord circuit so that when the call is released from the distant end, *LA* releases to light the cord circuit supervisory lamp at *LA*1. It is true that the current for this lamp passes over the sleeve circuit from the earth at the line termination, but this is merely to prevent the permanent lighting of the lamp when the cord circuit is not in use.

In the sleeve control system, the calling signal is not extended to the cord circuit, but a contact of the calling relay (*L*1) controls the resistance of the sleeve circuit in the line termination. Thus, whilst a call is in progress, *L*1 removes the short

circuit from the 5000 Ω coil of *S*, and the current in the sleeve circuit is insufficient to light the cord circuit supervisory lamp. When the call is cleared

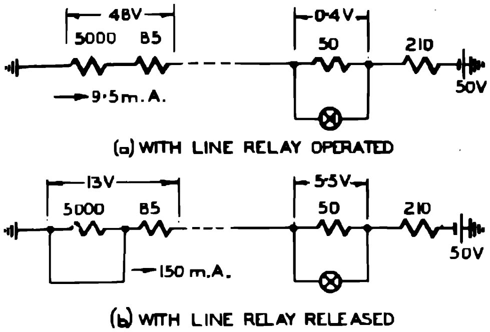


Fig. 521. P.D. Applied to Cord Circuit Lamp

at the distant end, *L* releases and *L*1 reduces the effective resistance of *S* to 85 Ω, thereby allowing the cord circuit supervisory lamp to light. The circuit conditions for the two states are illustrated in Fig. 521. With the line relay operated, there is approximately 9·5 mA in the sleeve circuit which results in a p.d. of about 0·4 V across the lamp. With the line relay released, the sleeve current is increased to about 150 mA which produces a p.d. of some 5·5 V across the lamp.

Key Supervision. On some circuits it is necessary to return a supervisory signal when an incoming call is answered by an operator. In the bridge control system, this facility is obtained by inserting speaking key contacts in the supervisory battery supply to the ring conductor of the cord circuit (Fig. 522 (*a*)). Thus, when the operator answers, a battery is returned on the *A*-wire to darken the supervisory lamp at the distant exchange. The lower part (*b*) of Fig. 522 shows the equivalent sleeve control arrangements. A differential relay *DR* is included in the line termination sleeve circuit. The resistance values are so adjusted that normally equal currents flow in the two windings of *DR*. The directions are such that the currents produce opposite magnetic effects and the relay does not operate. When an operator throws the speaking key, the resistance of the sleeve circuit is increased from about 240 Ω to 1400 Ω. The *DR* relay is now unbalanced and operates due to the preponderance of the current in the locally connected coil. ***DR*1** returns the supervisory battery on the *A*-wire. Fig. 523 shows the current distribution both before and after the speak key is thrown.

The simple insertion of additional resistance in the sleeve circuit when the operator answers would upset the normal circuit for the control of the supervisory lamp. It is therefore necessary to intercept and repeat the clearing signal if it should occur whilst the speaking key is thrown. The

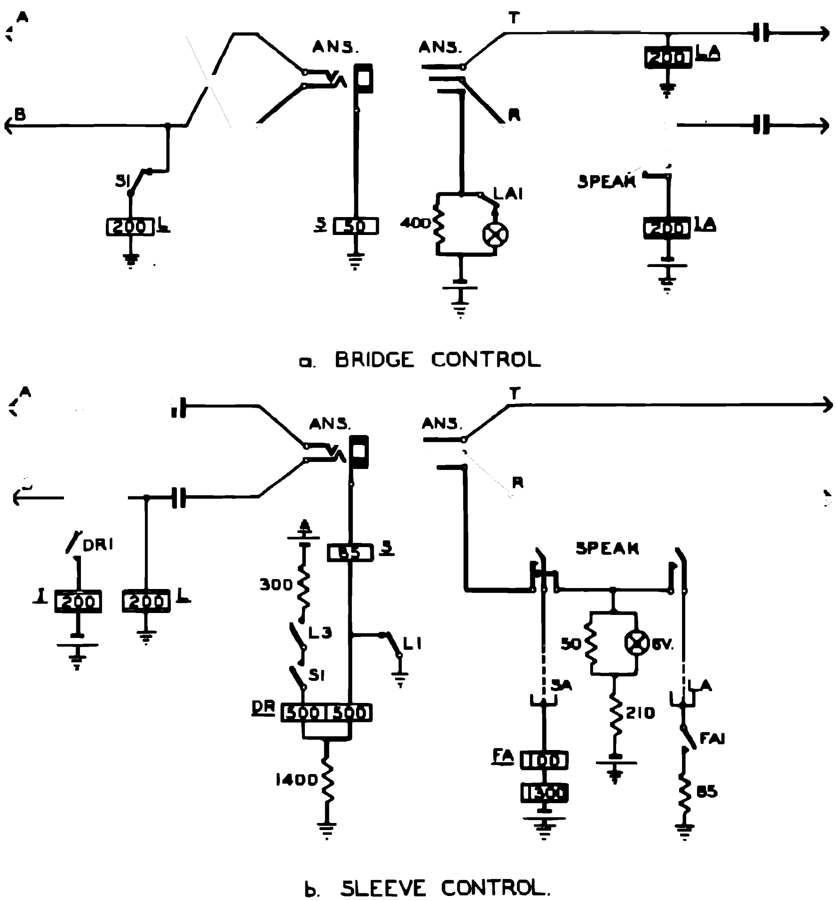


Fig. 522. Key Supervision

operator's position circuit contains a relay *FA* which is marginal and operates only when the

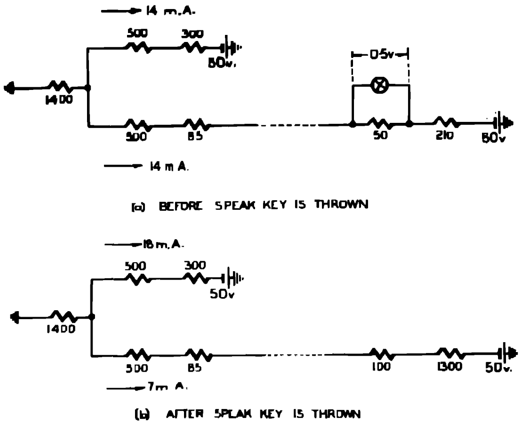


FIG. 523. CURRENTS IN *DR* RELAY

resistance of the line termination sleeve circuit is reduced to 85 Ω. The supervisory lamp circuit is extended by additional speak key contacts to the position circuit where an 85 Ω earth is applied when *FA* is operated. By this means, the supervisory lamp gives a visual clearing signal irrespective of whether or not the speaking key is thrown.

Through Clearing. The transmission of a clearing signal through an intermediate exchange to the originating exchange is obtained, in the bridge control system, by repetition from the cord circuit signalling relays. The supervisory battery on the *A*-wire operates relay *LC* (Fig. 524 (*a*)) which at ***LC*2** returns a battery via the ring conductor and the *A*-wire of the junction to the originating exchange. In the sleeve control system (Fig. 524 (*b*)), the supervisory battery received on the *A*-wire of an outgoing junction operates relay *LC* in the line termination. ***LC*1** applies a 2000 Ω battery via the ring conductor of the cord circuit to operate relay *TS* in the incoming line termination. ***TS*1** now repeats the supervisory battery on the *A*-wire to the originating exchange.

Automatic Signalling on Outgoing Circuits. In the bridge control system, C.B. signalling on outgoing

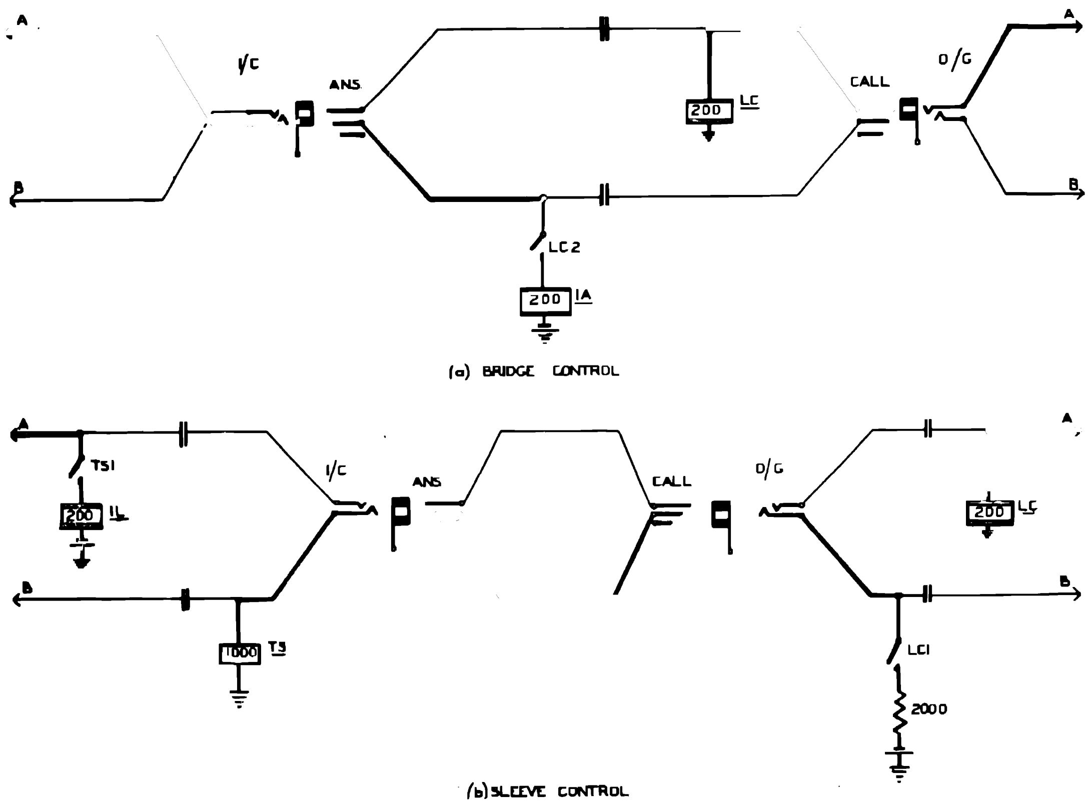


FIG. 524. THROUGH CLEARING

junctions is obtained automatically from the battery on the ring conductor of the calling cord (Fig. 525 (*a*)). Under sleeve control working, the operation of the *S* relay in the outgoing circuit automatically applies a calling battery on the *B*-wire (Fig. 525 (*b*)) from the line termination. The supervisory signal is returned to the cord circuit lamp in a manner similar to that already explained for incoming calls.

Forward Through Signalling. When the sleeve control manual board is a minor exchange it is necessary, on trunk calls, to extend the calling subscriber's clearing signal to the group or zone centre for the purpose of controlling the timing mechanism. In these circumstances, the appropriate circuits are provided with *forward through clearing*. Fig. 526 shows the circuit arrangements in the incoming and outgoing terminal relay sets at the minor exchange. The call is set up in the usual manner, and when the distant trunk operator answers, relay *LA* operates. ***LA*1** connects the 100 Ω *TS* relay to the ring conductor of the cord circuit to operate relay *CL* in the incoming relay set. Whilst the calling subscriber's receiver is off, relay *L* is operated and at ***L*2** the short circuit is removed from the high resistance coil of *CL*. Relay *TS* does therefore not operate at this stage.

When the calling subscriber clears, *L* releases but the ***CL*1** contact prevents the lighting of the cord circuit supervisory lamp. *L*2 reduces the resistance of the ring conductor circuit and thus allows relay *TS* in the outgoing termination to operate. ***TS*1** removes the calling battery from the *B*-wire of the outgoing junction to give a clearing signal at the distant trunk exchange. In due course, the trunk operator takes down the connexion and so disconnects the supervisory battery returned on the *A*-wire to the minor exchange. Relay *LA* now releases and at *LA*2 lights the calling cord supervisory lamp. *LA*1 disconnects the circuit for *CL* and *TS*, contact *CL*1 now completing the answering cord supervisory lamp circuit. It should be noted that, when forward through signalling is provided, no clearing signals are received by the minor exchange operator until the trunk operator takes down the connexion.

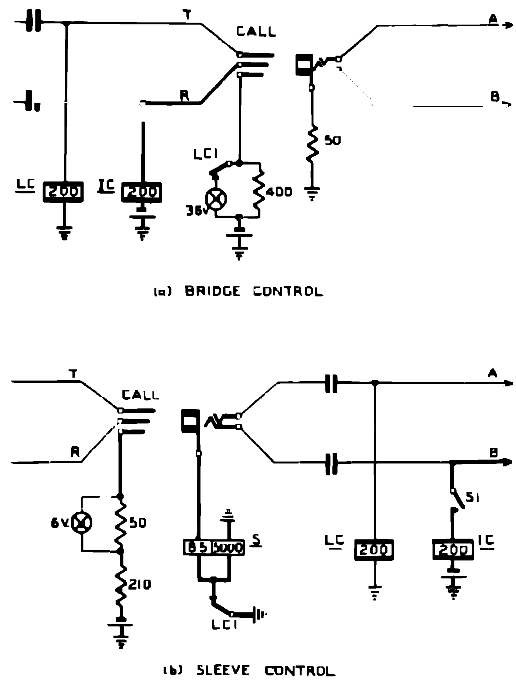


Fig. 525. Automatic C.B. Signalling on Outgoing Junctions

Cord and Position Circuits. The cord circuit of a sleeve control switchboard merely contains the supervisory lamps, a speaking key, and a monitoring key, together with two switching relays to associate the cord circuit with the operator's position circuit. The position circuit on the other

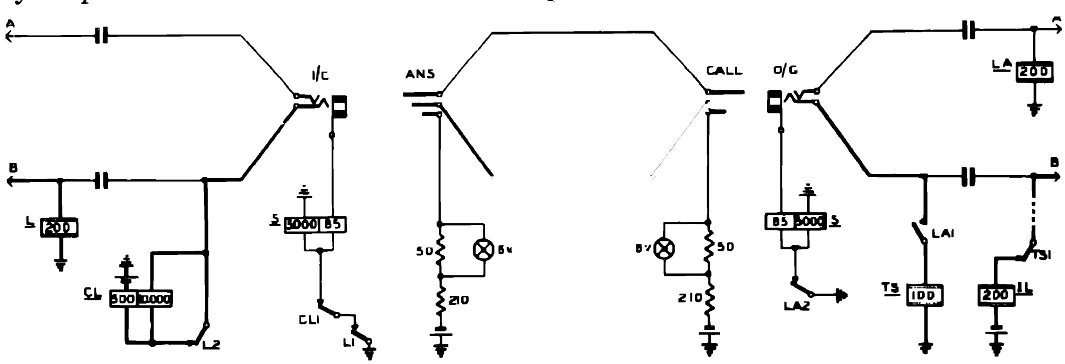


Fig. 526. Forward Through Signalling

hand contains the speaking and signalling circuits together with all the associated equipment. The following common keys are provided per position:

SPEAK CALL—SPEAK ANS. A double throw key which enables the operator to split the two sides of the cord circuit and to speak to either side at will.

RING/FLASH CALL—RING/FLASH ANS. A double throw key by means of which the operator can ring or recall on either the answering or calling sides of the cord circuit.

DIAL CALL—DIAL ANS. A double throw key to enable the operator to dial either on the answering or calling plug.

TRANSFER CALL—TRANSFER ANS. A double throw key which enables the operator to transfer to another suite a call held either on the answering or the calling cord.

COUPLE RIGHT—CALL SUPERVISOR. The key thrown in one direction couples the position circuit to the adjacent position on the right. When the key is thrown in the other direction, it operates the call supervisor circuit.

The main features of the cord and position circuits, with the detailed connexions of the common keys omitted, are illustrated in Fig. 527. Owing to the large number of leads to be switched to the position circuit it is not practicable to make direct use of the cord circuit speaking key contacts. Two relays *SK* and *SL* are therefore introduced for this purpose. When the speaking key is thrown both coils of relay *SK* are applied in series to a common 400 Ω battery in the position circuit. *SK* operates and at ***SK*4** holds the *SK* relay on its 50 Ω winding. ***SK*2**, ***SK*3**, ***SK*5**, and ***SK*6** switch the tip and ring conductors of both the calling and answering cords to the position circuit. It will be noted that, although the cord circuit is split at ***SK*3** and ***SK*6**, the two sides are connected together through the position circuit until one or other of the common keys is operated. ***SK*1** operates *SL* and the ***SL*1**, ***SL*3**, ***SL*5**, and ***SL*6** contacts similarly extend the sleeve and lamp circuits to the position.

The *SK* relay has marginal hold adjustments which prevent two *SK* relays being switched to the position circuit at the same time. Fig. 528 shows the current values under the several conditions. At the lowest permissible exchange voltage (46 V), there are approximately 24 mA in the two coils of *SK* when one speaking key only is thrown. When two speaking keys are thrown concurrently, there are approximately 22 mA in each of the two testing relays (Fig. 528 (*b*)) when the exchange voltage is a maximum. There is no possibility of marginal adjustment here, and both *SK* relays will operate when two speaking keys are thrown. An examination of Fig. 528 (*c*) (*d*), however, shows that when one *SK* relay only is switched the hold current is about 102 mA, whilst if two relays attempt to hold to the common resistor, the current in each is only about 61 mA. Thus, by designing the *SK* relay to release with, say, 70 mA, double switching is prevented.

The operator's telephone circuit is of conventional design with rectifiers for acoustic shock absorption. There is an additional monitoring transformer to enable the operator to supervise or *monitor* a call without introducing any appreciable transmission loss. The monitoring and speak keys of the cord circuit form a single double throw key. When the key is thrown to "monitor," the speaking pair is extended to the high impedance primary winding of the monitoring transformer via a 2 μF condenser. At the same time relay *M* is operated and at ***M*1** switches the receiver from the regular transformer to the secondary of the monitoring transformer. The circuit is so arranged that the *M* relay cannot be operated if any speaking key on the position is thrown. (Relay *MN* is operated when the speak key is thrown and disconnects the *M* relay circuit at ***MN*1**.) The 40 000 Ω resistors at various parts of the operator's transmission circuit are provided to "wet" the various contacts which would otherwise have no d.c. potentials applied to them (see Chapter VI).

The engaged test arrangements are interesting. Normally, the tip conductors of both the calling and answering plugs are connected at *TA*1 and *TC*1 to the primary of an engaged test transformer, the secondary of which is coupled to the receiver circuit. When the tip of either plug encounters a battery potential on the bush of a jack (the engaged condition) the charging current into the 0·5 μF condenser produces a click in the receiver. When a plug is inserted into any jack, relay *TA* or *TC* operates irrespective of the supervisory condition existing on the sleeve of the line termination. ***TA*1** or ***TC*1** disconnect the engaged test circuit and switch the tip conductor through to the secondary of the operator's induction coil. By this arrangement, it is possible to provide an operator's speaking circuit which is free from earth connexions and of the maximum transmission efficiency.

The *FA*—*TA* and *FC*—*TC* relay combinations in the sleeve circuits are shunted with a large condenser and a metal rectifier to absorb the high

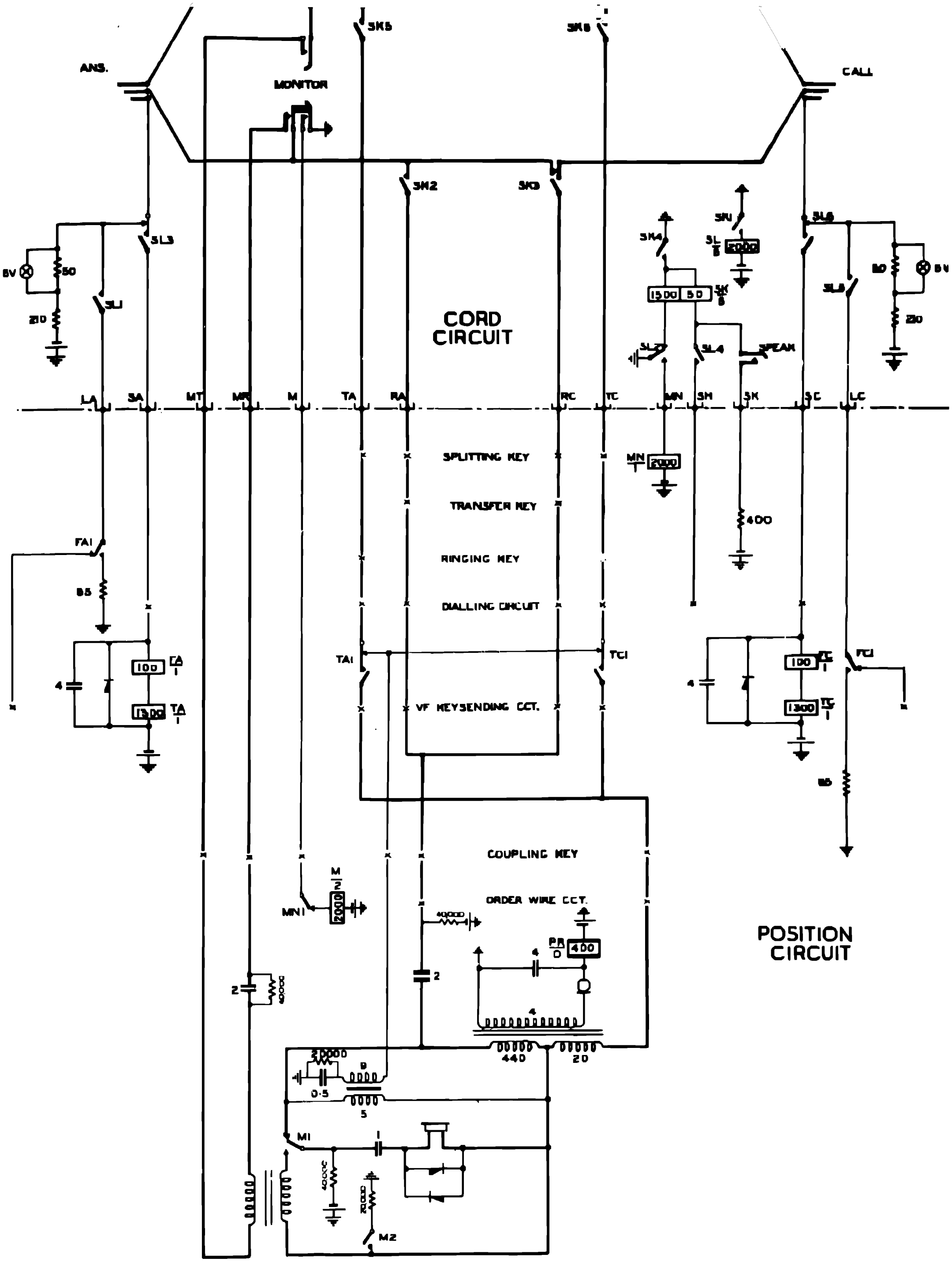


Fig. 527. General Arrangements of Position and Cord Circuits

induced e.m.f. when a plug is withdrawn from a jack, and so to prevent the possibility of electric shock to the operator.

Transfer Facility. In certain circumstances it is necessary to transfer a call, which is answered on one suite, to a second suite for attention. Such conditions exist when, for example, there are separate trunk and toll suites. Ordinary subscribers dial different codes for the two services

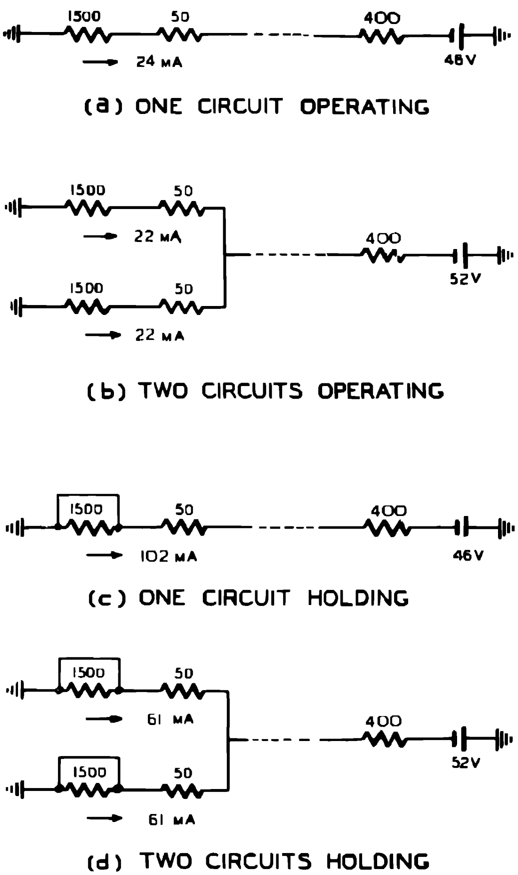


FIG. 528. CURRENTS IN *SK* RELAY

(e.g. 0 and 94) but all coin-box calls are received on the toll suite. Thus, if a long distance call originates from a C.C.B. subscriber the toll suite operator must transfer the call to the trunk suite. One method is to extend the caller over a "transfer" circuit, but a more rapid method is to multiple the incoming lines over both suites and to provide a means of switching the calling signal from one suite to the other. Manual board circuits which require the transfer facility have an additional relay *TR* (Fig. 529) connected to the ring conductor of the termination. A metal rectifier in series with *TR* ensures that the relay operates only on receipt of a positive battery. When a call is required to be transferred, the operation of the position transfer key sends out positive battery via a 100 Ω resistor on the ring of the cord circuit to operate *TR* in the line termination. A change-over contact of *TR* changes over the calling signal from the normal lamp circuit to that on the transfer suite whilst a second contact (***TR*2**) holds the *TR* relay for the duration of the call.

Splitting Key. The double throw speak-call/speak-ans. key is often known as the *splitting key* on account of its function of dividing the cord circuit. The connexions are as shown in Fig. 530. It will be observed that the key is non-locking in order to guard against an accidental break in an established connexion. An important feature of the sleeve control system is the provision of terminal impedances. It was seen in Chapter V that, in order to maintain stability in an amplified circuit, it is necessary to maintain a more or less constant impedance at the two-wire ends of the circuit. The impedance is standardized at 600 Ω. To obtain this requirement, long distance trunk circuits are terminated by a 600 Ω non-inductive resistor, and a 1 μF condenser is inserted to break the d.c. path. When an answering plug is inserted into a trunk line jack a contact of the sleeve relay (*S*) disconnects the terminal impedance to prevent the unnecessary transmission loss. Until the call is extended to another line, a replacing terminal impedance is provided in the operator's position circuit. This impedance is so connected that, when the splitting key is operated, the terminal impedance is connected to the "open" side of the cord circuit; thereby preventing an open circuit on the trunk which is temporarily cut-off.

Ringing and Flashing Circuit. The two-way ringing and flashing key in the position circuit provides facilities for ringing on generator signalling circuits and for the flashing of the distant exchange supervisory lamp on incoming and outgoing automatic signalling circuits. At some of the larger trunk exchanges a ring/flash key was provided per cord circuit, but this practice has now been abandoned in favour of the standard common key per position.

In manual exchanges of the bridge control type, ringing current is sent out from the cord circuit on operation of the ringing key. In the sleeve control system, there is no ringing supply to the manual positions but ringing current is applied at the line termination relay set in response to a d.c. signal from the position circuit. When an operator desires to ring, flash, or recall on any line she

momentarily throws the ring/flash key which applies a 100 Ω battery to the tip conductor of the cord circuit (Fig. 531). This battery, in turn, operates an *RR* relay connected to the tip circuit of an incoming C.B. signalling circuit to provide the supervisory condition. The flashing of *RR* therefore interrupts the supervisory signal to flash the cord circuit lamp at the distant exchange.

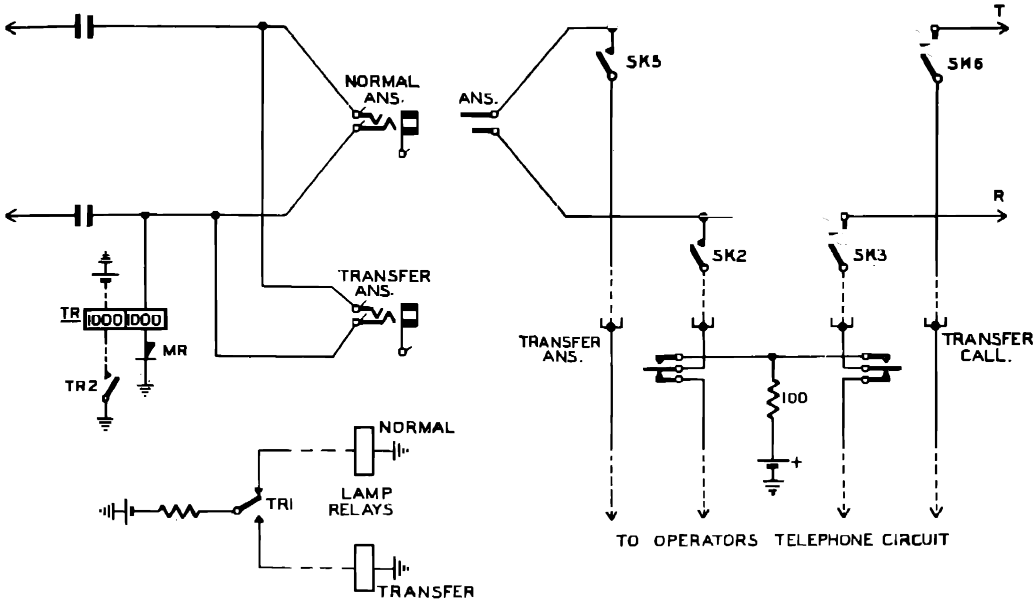


FIG. 529. TRANSFER FACILITY

of the line termination. The contacts of *RR* are arranged to suit the individual signalling conditions of the line. Fig. 531 shows three common arrangements. At (*a*) contact *RR*1 is connected in series with the battery which is returned on the *A*-wire Diagram (*b*) shows a similar arrangement on an outgoing C.B. signalling circuit. In this case the operation of *RR* interrupts the calling battery on the *B*-wire. On generator signalling junctions and where a subscriber's line is terminated directly on

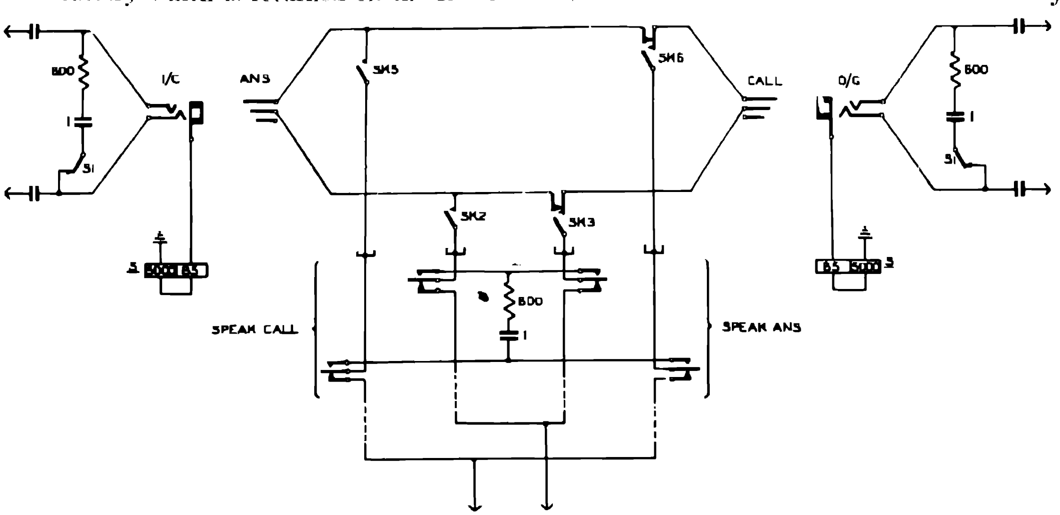


FIG. 530. SPEAK-ANS/SPEAK-CALL KEY CIRCUIT

a sleeve control switchboard, the operation of *RR* applies 17 c/s ringing current to the line for calling or recalling (Diagram *c*). Until quite recently, manual board circuits from an automatic exchange gave facilities for re-ringing the calling subscriber. The circuit arrangements were similar to (*c*) but the facility has now been abandoned.

Dialling Circuit. A two-way locking key in the relays *DC* and *DD* are operated. ***DD*2** and ***DD*3** switch the calling cord from the operator's telephone circuit to the dial circuit, but a secondary path is provided to the telephone circuit via ***DC*4**, ***DC*5** and the 2 μF condensers. This secondary path enables the operator to listen for tones between impulse trains during the setting up of a call. ***DC*7** applies a 2500 Ω battery via the retard

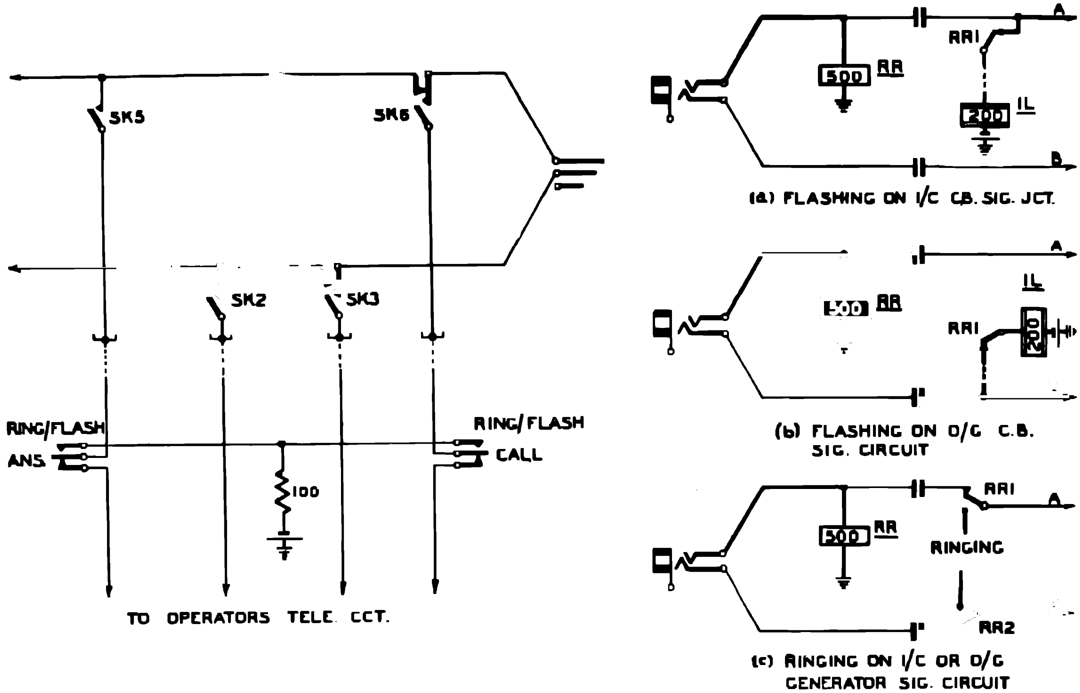


FIG. 531. RINGING AND FLASHING CIRCUIT

position circuit provides facilities for dialling on either the calling or answering cords. The position circuit is arranged to transmit loop impulses, and when battery dialling is required the outgoing junction relay set provides for the necessary conversion. In order to remind the operator, all outgoing dialling circuits are arranged to give a continuous flicker on the cord circuit supervisory lamp when a plug is inserted in an outgoing jack, until the dial key is thrown.

The appropriate elements of the position circuit and of the outgoing junction relay set are shown in Figs. 532–534. When a calling plug is inserted in the outgoing junction jack, relay *S* operates (Fig. 533). Flicker earth is connected to the centre point of the *S* relay (via *LR*2 and *DT*4) and, during each application of earth, relay *FC* in the position circuit operates to light the calling cord supervisory lamp. When the dial key is operated (assume "dial-call") *I* to the tip and ring of the calling plug. This battery operates relay *RR* in the tip circuit of the line termination. (Fig. 533). ***RR*1** in turn operates *DT* and the latter locks to its own contact ***DT*3**. ***DT*1** and ***DT*2** short-circuit the line termination condensers to provide a d.c. dialling loop from the position circuit to the distant automatic exchange. ***DT*4** breaks the flicker earth circuit and extends the *LR* relay to the sleeve circuit. The *LR* relay does not, however, operate at this stage due to the insertion of a 3000 Ω resistance (*YH*) by ***DC*6** (Fig. 532.) The circuit is now ready for dialling to commence.

When the dial is rotated, the off-normal contacts ***DON*2** operate relay *DK* via ***DC*1**. ***DK*2** and ***DK*3** disconnect the listening circuit and ***DK*2** completes the circuit for the dial impulse springs, whilst ***DK*4** removes the battery from *I*. The impulses are transmitted to line during the return of the dial

and, when the off-normal contacts restore, the circuit for *DK* is broken. After a period of lag *DK* releases and the call is held by the two windings of *I* in series. It will be noted that the impulsing

When dialling is completed, the operator restores the dial key and relay *DC* releases. After a release lag period, relay *DD* also releases. During the release lag of *DD*, a 500 Ω battery is applied via

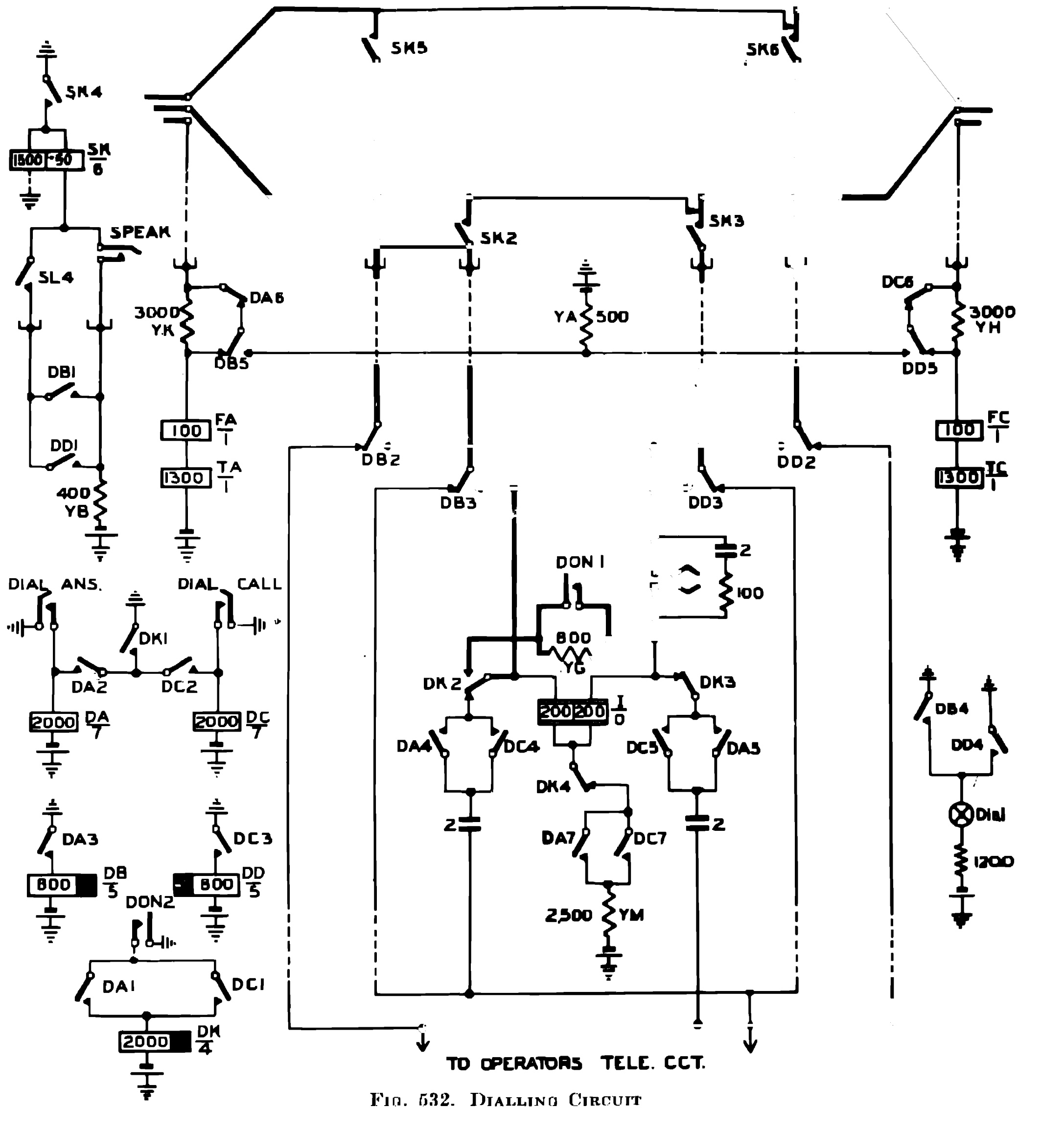


FIG. 532. DIALLING CIRCUIT

loop is first broken at *DON*1 and the 800 Ω resistance provides a holding circuit for the automatic selectors until the impulsing circuit is completely broken at *DK*2. This enables *I* to become partially fluxed before *DK* releases in order to avoid the momentary fall of line current due to the inductance of *I*.

***DD*5** and *DC*6 to the sleeve circuit to operate relay *LR* in the line termination. *LR* locks at ***LR*1** and by releasing *DT* at ***LR*4** (Fig. 533) removes the short circuit from the bridge condensers. ***LR*3** applies a high impedance holding loop (*IL*) to the line. Here again, the 800 Ω resistor *YB* provides a duplicate holding circuit until *DT*

releases in order to allow *IL* to be partially fluxed before the position circuit loop is broken.

Fig. 534 shows the alternative connexions of the junction relay set when battery dialling is required. Relays *RR* and *DT* operate when the dial key is

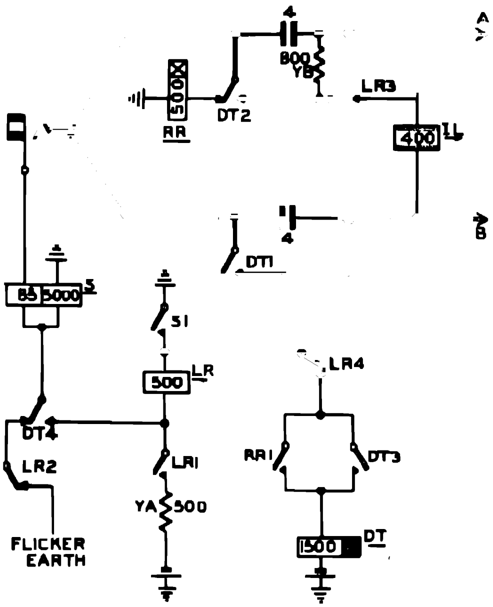


FIG. 533. ELEMENTS OF OUTGOING LOOP DIALLING CIRCUIT

thrown, and the incoming relay set at the automatic exchange is prepared for impulsing by the sending out of battery on both wires. The battery on the *A*-line is applied at ***DT*5**, whilst the battery at *YC* is connected via ***DT*2**, the position impulsing

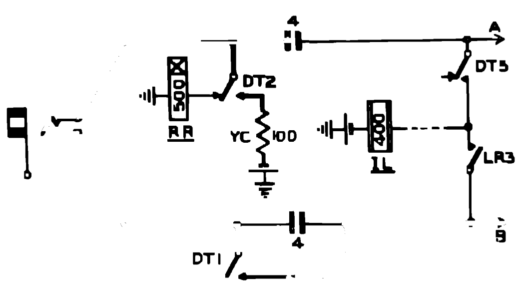


FIG. 534. ARRANGEMENT OF *DT* CONTACTS FOR BATTERY DIALLING

loop and ***DT*1** to the *B*-line. The impulses thus take the form of battery interruptions on the *B*-wire. The operation of *LR* at the end of dialling provides a holding battery on the *B*-wire from *IL* via ***LR*3**. The subsequent release of *DT* restores the normal conditions at *DT*1 and *DT*2, whilst *DT*5 removes the battery from the *A*-line to switch the circuit at the distant end to the speaking conditions.

Provision is made to prevent an interruption of the final impulse train due to premature restoration of the dial key. Relay *DK* (Fig. 532) is held until the dial returns to normal and at ***DK*1** holds *DC* independent of the dial key. Thus *DC* and *DD* cannot release until the impulse train is completed. Similarly, the circuit is so arranged that accidental restoration of the speak key cannot interrupt an impulse train. This locking is provided by contact ***DD*1** which holds relay *SK* via ***SL*4** independently of the speaking key contacts.

The operation of the dialling circuit on the

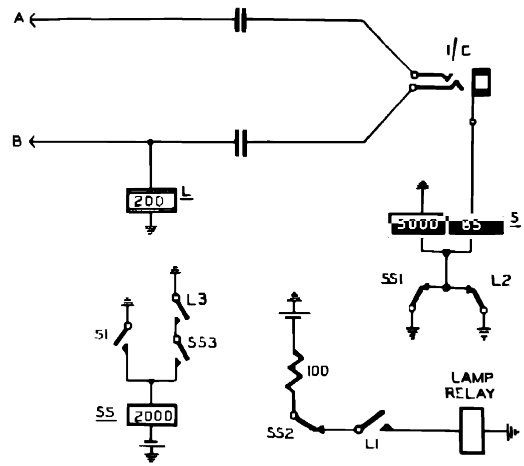


FIG. 535. CALLING SIGNAL LOCK-OUT FEATURE

answering cord is identical except that relays *DA* and *DB* are operated instead of *DC* and *DD*.

Calling Signal Lock-out. Multiple appearance of answering lamps is provided at all public sleeve control exchanges. To avoid difficulties which would occur if the operator withdrew the plug from an answering jack before the caller had cleared, all circuits are arranged to lock-out the calling signal after it has once been answered. The principle of the calling signal lock-out feature is illustrated in Fig. 535. *L* operates to the calling condition and energizes the multiple answering lamp relay at ***L*1**. When an operator answers by inserting a plug into a multiple appearance of the jack, *S* operates. Relay *SS* now operates from the earth at ***S*1** and locks to its own contact (***SS*3**) under the control of ***L*3**. ***SS*2** extinguishes the calling lamps and prevents a repetition of the calling signal until *L* and *SS* restore, when the calling party clears and the plug is removed from the jack. Fig. 535 also shows an *SS* contact (***SS*1**)

in parallel with $L2$. This is a common feature of all sleeve control circuits and has been provided as a matter of policy to give uniform conditions in the sleeve circuit at the moment a plug is inserted. The operator normally answers with the speaking key thrown, and under these conditions $SS1$ gives a large initial current to facilitate the operation of TA in the position circuit (see Fig. 527). Although the facility has not so far been found necessary, the arrangement could be made to prevent two operators seizing the same circuit. key is thrown. Similarly a through signalling condition transmitted over the ring conductor of the cord circuit operates relay TS to return the supervisory battery when the called subscriber answers. $SS3$ returns battery on the A-wire when the calling condition is removed from the outgoing end until such time as the plug is withdrawn from the incoming jack. It is, by this means possible to prevent re-seizure of the circuit until the previous call has been completely cleared.

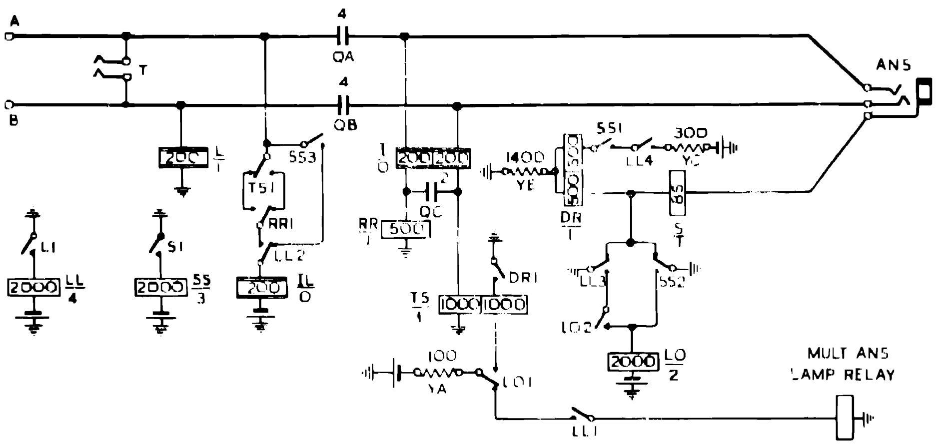


FIG. 536. INCOMING C.B. SIGNALLING JUNCTION

Incoming Junction C.B. Signalling. Fig. 536 shows a straightforward application of the various principles of sleeve control working. The circuit is designed for use on an incoming junction on which C.B. signalling is employed. The calling signal on the B-wire operates relay L which at $\boldsymbol{L1}$ energizes the relief relay LL. $\boldsymbol{LL1}$ now operates the multiple answering lamp relay. When the operator inserts a plug into the answering jack, relay S operates to the battery on the sleeve conductor and at $\boldsymbol{S1}$ operates SS. $\boldsymbol{SS2}$ operates the $\boldsymbol{LO}$ relay to obtain the calling signal lock-out feature, whilst $\boldsymbol{SS1}$ prepares the circuit for relay $\boldsymbol{DR}$ in readiness for the operator answering. When the operator throws the speaking key, the increase in resistance of the sleeve circuit causes an unbalance in the two coils of DR, which operates. $\boldsymbol{DR1}$ energizes TS, and $\boldsymbol{TS1}$ in turn returns the supervisory battery to the originating exchange on the A-line. The operator can flash the originating exchange at any time by the operation of the ringing key which, by applying battery on the tip conductor, operates relay RR. $\boldsymbol{RR1}$ disconnects the supervisory battery for so long as the ringing

Bothway Junction, Differential Signalling. The circuit of Fig. 537 employs the differential signalling principle described in Chapter XIII, and is used where the junction resistance is too great for the adoption of C.B. signalling.

The calling condition is battery on both wires which operates relay DL to the earth at $SS3$. $\boldsymbol{DL1}$ operates relay L, and $\boldsymbol{L4}$ operates the answering lamp relay. Contact $\boldsymbol{L3}$ energizes relay ET which at $\boldsymbol{ET1}$ and $\boldsymbol{ET2}$ completes the F.L.S. lamp relay circuit and applies the engaged test battery to the outgoing multiple jacks. When the operator answers, relays S and SS operate. $\boldsymbol{SS2}$, in turn, operates LO which at $\boldsymbol{LO3}$ disconnects the answering lamp relay. In accordance with the standard arrangements, DR operates due to the out-of-balance produced when the operator throws her speaking key. $\boldsymbol{DR1}$ now operates TS, and $\boldsymbol{TS1}$ replaces the earth at the centre point of DL by battery from X via $RR3$, $\boldsymbol{TS1}$, $\boldsymbol{L2}$, $\boldsymbol{SS3}$, and $MM1$. DL is now held on its local winding (to the earth at Y) whilst the line current is reduced to zero to give the supervisory condition to the distant exchange. Through supervision is similarly given when the called party replies, relay TS being

operated in this case by the battery on the ring conductor. When the calling condition is removed at the termination of the call, relays *DL* and *L* release and when the plug is removed from the incoming jack *S*, *SS*, *LO* and *ET* also release and the circuit is restored to normal. The function of contact *L2* is interesting. On the release of *DL* and *L*, *L2* applies battery to line to lock out the battery to line. Relay *DL* does not operate at this stage due to the balance of currents in its windings. ***MM4*** operates *LO* and ***LO3*** energizes the F.L.S. relay. When the operator at the called exchange answers, an opposing potential reduces the line current to zero and *DL* now operates to the current in the local winding. ***DL1*** operates *L* and ***L6*** removes the earth from relay *M* to darken the cord

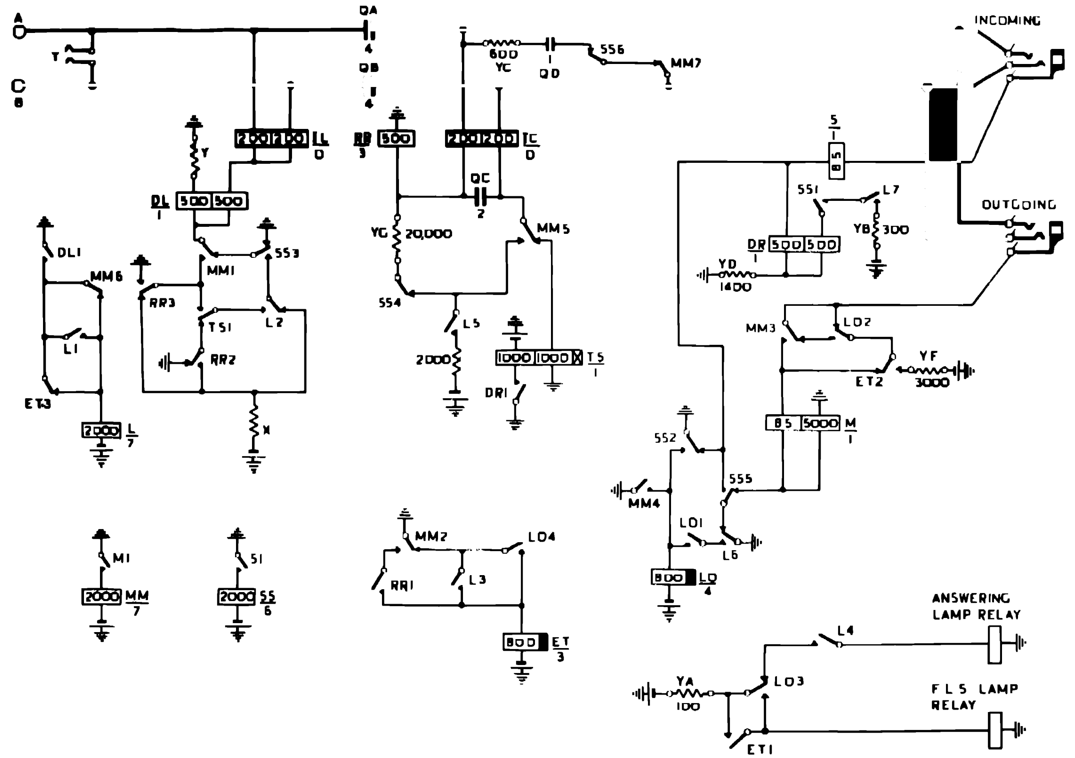


Fig. 537. Bothway Differential Signalling Junction

distant calling equipment and to engage the line at the distant end until the plug is withdrawn at the incoming end. Flashing facilities are provided by the operation of *RR* which at ***RR2*** or ***RR3*** removes or applies the supervisory condition. (***RR2*** functions if *TS*1 is normal, and *RR*3 controls the flashing when ***TS1*** is operated.) Relay *TS* is fitted with an armature end slug to prevent an interaction between relays *DR*, *TS* and *L* if *DR* flicks before the speaking key is thrown.

On outgoing calls, relay *M* operates on the insertion of a plug into the outgoing multiple. ***M1*** operates *MM* and ***MM1*** sends out the calling circuit supervisory lamp. At the same time, ***L5*** connects the 2000 Ω through signalling battery to the ring conductor. The flashing facility is available on outgoing calls, but an additional contact ***RR1*** operates the *ET* relay. ***ET3*** in turn releases *L* for the duration of the flashing period to disconnect the through signalling battery at *L5*. At the termination of an outgoing call, the withdrawal of the plug releases *M* and *MM*. *MM*2 operates *ET* which maintains the engaged condition. If the plug remains in the jack at the incoming end of the circuit, battery is returned to operate *DL* at the outgoing end. *DL*, in turn, operates *L*, and ***L6***

holds relay *LO* via **LO1** before it has had time to release after the opening of the *MM*4 contacts. The *ET* relay is now held at **LO4** for so long as the plug is in the distant jack. The withdrawal of the plug at the incoming end allows relay *DL* to release and relays *L*, *LO* and *ET* restore in turn. Only when the circuit is completely normal are the engaged test and F.L.S. conditions removed.

provide a permanent supervisory condition. This arrangement is applied to all circuits which do not give automatic clearing in order to avoid the continuous glowing of a distant supervisory lamp during the progress of a call. **MM1** merely provides a "wetting" battery to the tip conductor.

On an incoming call, relay *L* operates to the 17 c/s current received from line and at **L1** operates

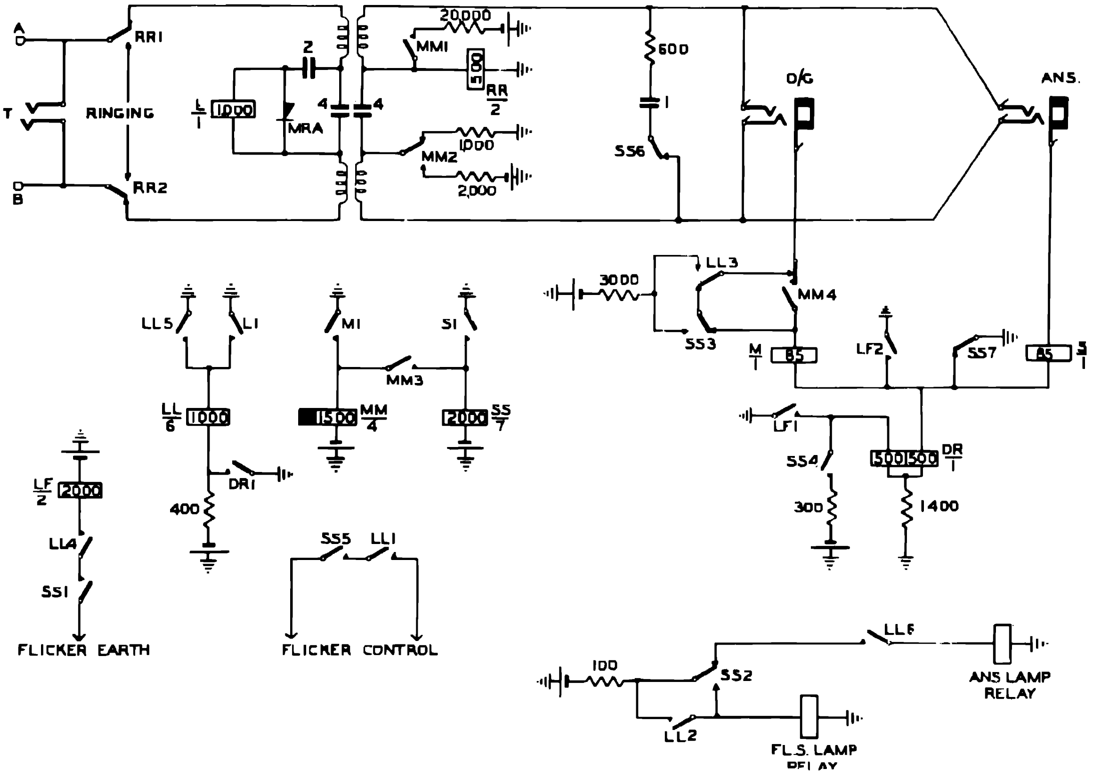


Fig. 538. Bothway Generator Signalling Trunk Circuit

Bothway Generator Signalling Trunk. Fig. 538 shows the circuit of the terminal relay set for a long distance generator signalling bothway trunk circuit.

On an outgoing call relay *M* operates when a plug is inserted into a multiple jack. *M1* operates *MM* and *MM3* in turn operates *SS*. *SS2* operates the F.L.S. relay whilst *SS7* disconnects full earth from relay *M* to darken the cord circuit supervisory lamp. *SS6* disconnects the terminal impedance. The operator calls by throwing the "ring-call" key. Relay *RR* is operated to the battery on the tip and at *RR1* and *RR2* applies ringing current to line for so long as the ring key is operated. It will be noted that contact *MM2* connects 2000 Ω battery to the ring conductor to

LL. *LL2* operates the F.L.S. lamp relay whilst *LL3* connects engaged test battery to the outgoing jack. *LL5* holds *LL* independent of *L* and *LL6* operates the answering lamp relay. *S* operates when a plug is inserted into the incoming jack and at *S1* operates *SS*. *SS2* releases the answering lamp relay. Relay *DR* operates when the speaking key is thrown and in so doing releases *LL*. The *LL* contacts are, however, ineffective and no supervisory signal is returned to the originating exchange.

Should the distant exchange operator desire to recall the incoming exchange, she momentarily operates her ringing key. Relay *L* operates to the ringing current and energizes *LL* at **L1**. *LL4* connects flicker earth to the *LF* relay via *SS1*, and *LF* operates and releases to each cycle of

flicker earth. ***LF*2** connects earth to the sleeve circuit to flash the cord circuit supervisory lamp at flicker speed. Contact ***LF*1** shunts the battery supply in the local circuit of the *DR* relay to prevent its operation when the current in the two coils is unbalanced by the closure of ***LF*2**. When the operator answers the recall signal, *DR* operates to the unbalanced conditions during the release lamp relay and ***B*3** returns ringing tone to the caller. When the call is answered, relay *S* operates. ***S*1** operates *SS* which locks at ***SS*1**. ***SS*3** disconnects the ringing tone supply and ***SS*4** releases the answering lamp relay. ***SS*2** provides a manual hold earth to the *P*-wire independent of the calling subscriber. At the end of the call, the release of *L* lights the calling cord supervisory lamp at *L*1. If the auto-

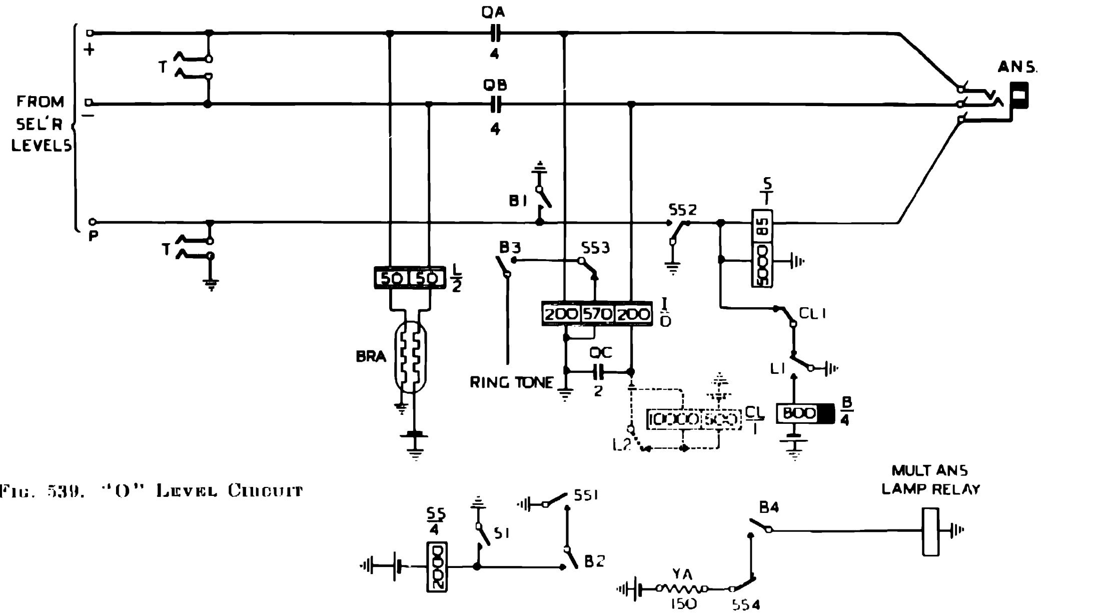


Fig. 539. "O" Level Circuit

period of *LF*. ***DR*1** releases *LL* and *LL*4 in turn disconnects the *LF* relay from the flicker supply. Contacts ***LL*1** and ***SS*5** are provided to start the flicker earth supply circuit.

It will be noted that relay *MM* is made slow to release in order to prevent the false operation of *M* to the engaged test battery when *SS*3 and *MM*4 restore.

By slight alterations in the *L* relay circuit, this termination can be used for d.c. signalling with an earthed relay connected to the centre point of the transformer or with the calling relay connected across the two-wire line. Similarly, outgoing d.c. signalling can be provided by connecting the *RR*1 and *RR*2 contacts to the appropriate battery and earth potentials.

"O" Level Circuit. A typical "O" level circuit from the first selector level of an automatic exchange to its parent automanual switchboard is illustrated in Fig. 539. The *L* relay operates to the calling loop and at ***L*1** energizes relay *B*. ***B*1** returns a holding earth on the *P*-wire to the automatic selectors, whilst ***B*4** lights the answering

manual switchboard is a minor exchange, forward through signalling must be provided in order to extend to the group centre operator the supervisory condition from the calling subscriber. In these circumstances relay *CL* is provided and the forward through clearing signal is passed through the cord circuit on the ring conductor as already described.

It is apparent that Fig. 539 can be used only when the sleeve control automanual board is in the same building as the automatic equipment. If the automatic exchange is remote from the parent exchange, a modified circuit is required in order to return the manual hold condition over the *A*-wire of the junction (see Chapter XIII).

Assistance Circuit with Transfer Facility. Fig. 540 shows an assistance circuit from an automatic exchange where facilities are required for transferring a call to another suite of positions in the same building. The general operation of the circuit is similar to Fig. 539. If, after answering a call, the position transfer key is operated, the positive battery on the ring conductor operates *TR*. ***TR*3**

provides a holding circuit for *TR* whilst ***TR*1** disconnects relay *S* and lights the answering cord supervisory lamp by applying an 85 Ω earth to

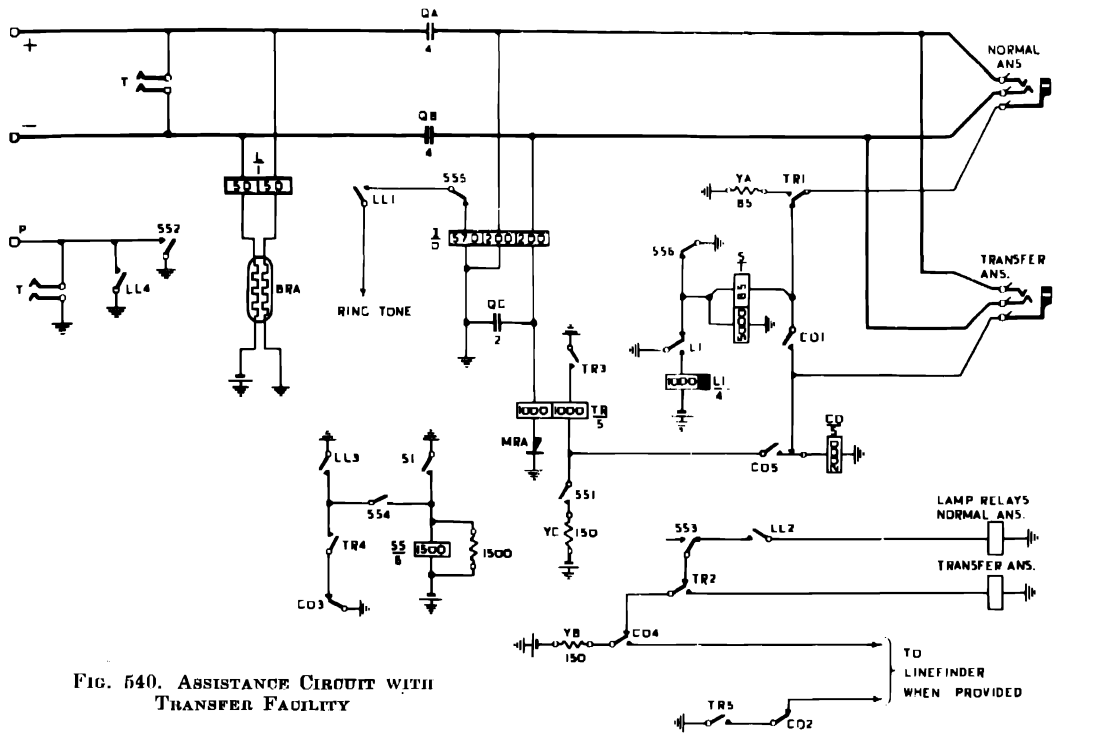


FIG. 540. ASSISTANCE CIRCUIT WITH TRANSFER FACILITY

the sleeve circuit. The normal operator can now withdraw her answering plug. ***TR*4** provides an alternative holding circuit for *SS* to guard against the release of *L* and *LL* before the call is answered at the transfer position. ***TR*2** lights the calling lamps on the transfer suite. When the call is answered, relay *CO* operates to the battery in the sleeve circuit and locks to the 150 Ω battery at ***SS*1**. ***CO*1** now connects the *S* relay to the transfer suite sleeve circuit whilst ***CO*4** disconnects the calling lamp. The call now proceeds as on an ordinary "0" level circuit.

In some cases, a very large number of circuits may require transfer facilities but the volume of transferred traffic may be small. In these circumstances it is uneconomical to duplicate a large part of the normal answering multiple on the transfer suite. A linefinder scheme is therefore adopted. Transfer answering equipments to meet the maximum traffic are arranged in a common pool (Fig. 541) and are connected to the regular answering equipments via a linefinder. An allotter circuit determines which transfer linefinder shall search for each transferred call. When the circuit of Fig. 540 is used in connexion with a linefinder scheme, the start condition is transmitted to the linefinder when ***TR*5** operates.

Outgoing Junction, Loop Dialling. Fig. 542 shows an outgoing junction termination arranged for loop dialling to an automatic exchange. It employs

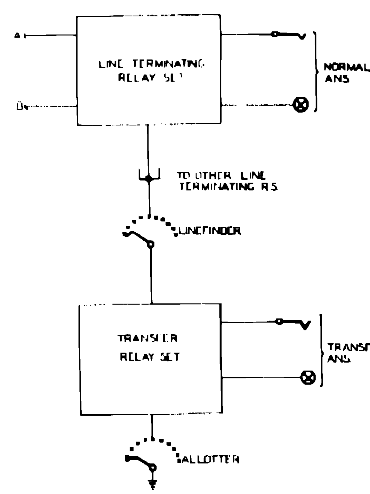


FIG. 541. TRANSFER LINEFINDER SCHEME

the principles already considered in Fig. 533 for the transmission of loop impulses to line. When the call has been set up and the called subscriber answers, relay *D* operates to the reversal of the current from the automatic exchange. ***D*2** applies a 2000 Ω battery to the ring conductor for through signalling, whilst ***D*1** removes the earth from the *S* relay to darken the cord circuit supervisory lamp. If busy conditions are encountered, relay *IL* *YE* in readiness for impulsing on the *B*-line of the junction. ***DT*3** disconnects the flicker supply and connects the *LR* relay to the sleeve circuit. ***DT*4** disconnects the *D*-relay from the *A*-wire of the junction and applies battery via *IL* to seize the incoming relay set at the automatic exchange. ***DT*5** removes the *IL* battery from the *B*-line and replaces it by the battery via the dial impulse springs in the position circuit. It will be noted that

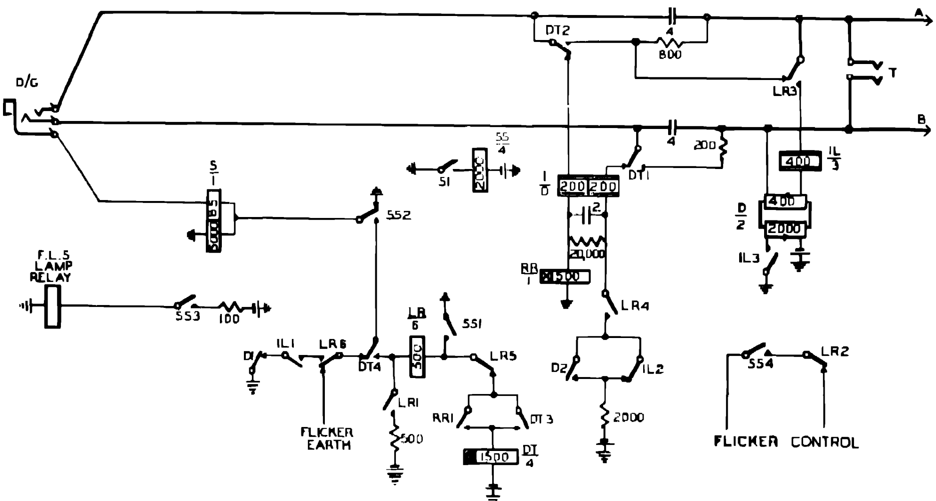


FIG. 542. OUTGOING JUNCTION, LOOP DIALLING

releases during each busy flash period. ***IL*1** flashes the cord circuit supervisory lamp whilst ***IL*2** flashes the through supervisory battery.

The retard *I* and the 2 μF condenser balance the impedance of the speaking pair to earth. The 20 000 Ω resistor is the usual "wetting" leak. In the actual relay set, facilities are provided for cutting out the 200 Ω resistor in the *B*-line impulsing circuit to obtain better dialling conditions on high-resistance junctions.

Outgoing Junction Battery Dialling. Fig. 543 shows a typical outgoing junction termination arranged for battery dialling. The circuit is substantially similar to the loop dialling termination except for the arrangement of the *DT* contacts. When the position dial key is operated, battery is fed out from the position circuit to both the tip and the ring of the outgoing jack (Fig. 532). At the same time the sleeve circuit resistance is increased by 3000 Ω to prevent premature operation of relay *LR*. The battery on the tip conductor energizes relay *RR* which at ***RR*1** completes the circuit for *DT*. ***DT*2** removes the short circuit from the 4000 Ω resistor *YE* and connects battery via ***YB*** to the tip conductor to hold relay ***RR*** via

*DT*5 is of the make-before-break type to prevent a false impulse during this period of change over.

When the dial is rotated from its normal position, the balanced battery condition from the position circuit to the tip and ring conductors of the cord circuit is replaced by a dry loop (see Fig. 532). Battery is now fed to the *A*-line of the junction via retard *IL* and contact ***DT*4**, whilst the battery on the *B*-line is supplied from *YB*, ***DT*2**, the loop formed by the dial impulse springs and contact ***DT*5**. Hence, during dialling, the battery is maintained on the *A*-wire, but the battery on the *B*-wire is interrupted at each break impulse of the dial.

At the completion of dialling the position circuit dial key is restored to normal, which results in a decrease of the sleeve circuit resistance. Relay *LR* now operates, and at ***LR*4** applies a holding battery to the *B*-line of the junction. ***LR*5** releases relay *RR*, and *RR*1 in turn releases *DT*. *DT* in releasing removes the battery from the tip conductor at *DT*2, and at *DT*1 prepares the circuit for the through signalling condition. *DT*3 disconnects relay *LR* from the sleeve circuit and applies con-

tact *D*1 in order to place the cord circuit supervisory lamp under the control of the *D*-relay. When the called party answers, relay *D* operates to battery applied at the distant end to the *A*-wire, and at ***D*1** darkens the calling cord supervisory lamp. At the same time ***D*2** applies the normal through signalling battery (via 2000 Ω) to the ring conductor of the cord circuit.

Relay *RR* is made slow to operate in order to make it immune from the effects of condenser surges during dialling. The slow release feature of *RR* also permits the locking of relay *LR* via ***LR*1** before the initial operating circuit at ***DT*3** is broken. It will be noted that during dialling *RR* is held from the battery at *YB* and hence is in parallel with the dialling circuit. The shunting effect is minimized by the introduction of the 4000 Ω resistor *YE*.

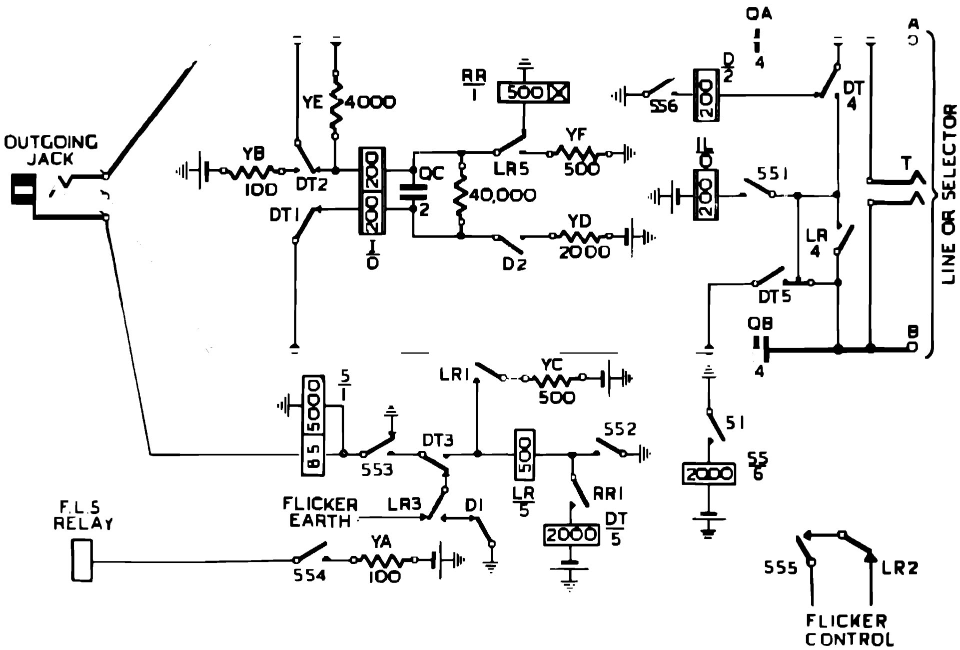


FIG. 543. OUTGOING BATTERY DIALLING JUNCTION

EXERCISES XVIII

1. Compare, with the aid of circuit diagrams, the Bridge Control and the Sleeve Control systems of providing supervisory signalling facilities in telephone exchange cord circuits. State the reasons for using the Sleeve Control system in trunk working. (*C. & G. Telephony, Grade II*, 1942.)

2. Describe, with the aid of a circuit diagram, how the cord circuit supervisory lamps are controlled at a trunk-demand switchboard of the sleeve-control type (*a*) when the "speak" key is normal. (*b*) when the "speak" key is operated, and (*c*) when the "dial" key is operated. Quote typical resistance values for the components, to illustrate the increase and decrease of current in the lamp control circuit under the various conditions. (*C. & G. Telephony, Grade II*, 1945.)

3. Enumerate the main features of the sleeve control system for manual switchboards. Give simple diagrams showing (*a*) how a cord circuit is linked up with the position circuit, and (*b*) how the cord circuit supervisory signals are controlled. (*C. & G. Telephony, Grade II*, 1939.)

4. Prepare, from the principles described, a diagram for the Sleeve Control termination of an outgoing C.B. signalling junction.

5. Describe, with explanatory diagrams, how through signalling is provided at a sleeve control exchange.

6. What is meant by "forward through signalling"? When is it used and how is the signal passed through the cord circuit at a sleeve control exchange?

7. It is not possible, at a sleeve control exchange, to place two conversations in contact by operating both speak keys together. How is this feature obtained?

8. Although there is a transmission bridge in all outgoing dialling circuits at a sleeve control exchange, it is possible to dial through the bridge without repeating the impulses. Show by means of simple diagrams how this is done.

9. A sleeve control position circuit is so arranged that, if the speak key is accidentally restored, any impulse train in course of transmission is not interrupted. Describe the circuit details concerned.

10. Show how the calling signal of an incoming circuit at a sleeve control exchange is disconnected for the duration of the call once the call has been answered.

11. Design, for a sleeve control exchange, an outgoing circuit termination with loop calling and forward through clearing.

CHAPTER XIX

AUTOMANUAL AND TRUNK EXCHANGES

TRUNK and junction circuits have already been considered in Chapter XII in connexion with the subdivision of the country into zones, groups, etc. Briefly, any circuit which connects two exchanges and involves the payment of more than four unit fees at the full day rate is classified as a trunk circuit. At the present time any circuit of more than 15 miles in length is, under the above definition, a trunk line, whereas circuits of less than 15 miles in length are classified as junctions. A *trunk exchange* is an exchange which is primarily devoted to the handling of calls over demand trunk routes. All zone and group centres may therefore be considered as trunk exchanges. Other manual exchanges and automanual switchboards may of course control calls on circuits more than 15 miles in length, but they are "minor exchanges" in the main trunk network and are not therefore proper to be classified as trunk exchanges.

Junction circuits being short in length and comparatively inexpensive are invariably provided in sufficient numbers to enable all normal traffic to be completed as it originates. There may nevertheless be occasional abnormal peaks of traffic when the operator will find all junctions on a particular route engaged. It is economically impossible to provide sufficient circuits to meet such abnormal demands and all calls which cannot be completed due to momentary congestion are considered as lost, the calling subscriber being informed that the junctions are engaged.

Long distance trunk lines, on the other hand, and particularly the zone-to-zone centre links, are very expensive to provide and economic considerations play a far greater part in the standards of provision. It is also of great importance that the operating methods shall be such that the effective call time (often known as the *paid time*) of each circuit shall be a maximum. In this connexion it is interesting to note that even with the modern highly mechanized system of trunk line operating it is difficult to obtain appreciably more than 30 min. paid time in any one hour. The lost time is due partly to the irregularities of traffic flow, and partly to the time necessary for the call to be established and for the called party to reply.

Operating Methods. There are three recognized methods of operating trunk lines:

No Delay working, in which sufficient circuits are provided for all calls to be completed as they originate. This is the same basis as for junction circuits and is economically practicable only on the shorter trunk lines. On the other hand, the service given to the telephone subscribers is excellent and with the rapidly advancing technique of carrier telephony it is possible that in a few years' time the provision of circuits on a no delay basis, irrespective of length, will become standard.

Delay working in which the calling subscriber books all long distance calls and is later rung by the trunk operator when it is his turn for the use of the trunk lines. By the adoption of delay working it is necessary to provide only sufficient trunk circuits to meet the *average* traffic over a period, the inevitable peaks of normal traffic flow being levelled out by the process of queuing-up all waiting calls at a special delay position. Delay working is, however, by no means ideal from the subscribers' point of view, and the booking procedure necessitates some degree of delay even at slack periods when the trunk circuits are free.

Demand working in which the bulk of traffic (apart from abnormal peaks) is completed within a predetermined period of say 1 min, the subscriber remaining on the line whilst an effort is made to complete the call. With demand trunk working sufficient circuits are provided to enable 85 per cent of the total busy-hour trunk traffic to be completed within the 1 min search period, the remaining 15 per cent of the calls being completed on a delay basis.

Trunk and Toll Exchanges. Until the year 1932 all long distance trunk circuits in the British Isles were operated on a delay basis. This principle has now been abandoned in favour of a system which combines no delay and trunk demand working. In general, all routes to exchanges within 50 miles radius of a particular switching centre are worked on a no delay basis. The 50 miles specified limit is adjustable to meet local conditions, and is modified somewhat for automatic exchanges which are themselves more than 50 miles distant but have their automanual switchboard within the 50 miles limit. The area inside which the circuits are worked on a no delay basis is known as the *toll area* for that particular exchange, and the short trunk circuits within the area are often referred to as *toll circuits.* The London Metropolitan Area is a special case and the London toll area comprises all exchanges whose group centres can be directly reached from

the London toll exchange. Circuits to exchanges outside a toll area are provided on a demand basis.

Due to the rapid expansion of automatic switching in the last few years all trunk exchanges with very few exceptions are also the automanual switchboards for one or more automatic exchanges. The standard arrangements at zone and group centres provide for the subscriber dialling one code only (i.e. "0") for all calls irrespective of the type of call, i.e. assistance calls, toll calls, or trunk calls. This method of operating is known as *joint trunk working*. There is one exception to the general use of "0" to obtain access to the joint trunk operator. Operators at exchanges which dial into the group or zone centre dial the digits "94." The "94" circuits are multipled over the answering field of the joint trunk positions and the trunk operator reverses all calls received over these circuits in order to secure switch-hook control (for purposes of call timing) from the originating subscriber.

At very large zone centres it is sometimes impracticable to accommodate all the junction and toll circuits together with the long distance demand trunk circuits in the outgoing multiple field. In these circumstances it is necessary to adopt separate *trunk and toll working*. The subscribers are then required to dial two separate codes for assistance and toll calls and for trunk calls. Usually level "0" is allocated for toll calls and "94" is dialled for trunk calls, except in director areas where the codes are TOL and TRU respectively. The toll and trunk level circuits are terminated on separate switchboards, one dealing with toll and assistance traffic only and the other dealing with long distance trunk traffic. By this means, the jack space required on each switchboard is considerably reduced since all the long distance trunk circuits and a proportion of the incoming circuits from selector levels are now accommodated on the separate trunk switchboard. It should be noted that, when separate toll and trunk working is adopted, certain types of call will require to be transferred from one switchboard to the other. The most important case is that of coin-boxes which dial "0" irrespective of whether the call is proper to the trunk or the toll exchange. The coin-box "0" levels normally appear on the toll suite and are extended when necessary by the operator over transfer circuits to the trunk suite.

In the London telephone area there are two toll exchanges in addition to a separate trunk exchange. The London Toll A exchange is a switching centre for traffic to exchanges in the London toll area which are beyond the 10-mile circle. Subscribers dial TOL for calls routed via the Toll A exchange. The second toll exchange is known as London Toll B and is a switching centre for calls coming from the London toll area to exchanges within the London 10-mile circle. The trunk exchange is entirely separate and is obtained by dialling the code TRU.

Apart from the greater flexibility obtained with joint trunk working one of the more serious difficulties with separate toll and trunk exchanges is the discrimination imposed upon the subscriber, who is required to know which exchanges are within the toll area and which exchanges are proper to trunks. It is for this and other reasons that separate toll and trunk working is avoided wherever possible.

Delay Trunk Working. Although delay working has now been abandoned in Great Britain a brief summary of the operating procedure is useful for comparison purposes. Under the trunk delay system the calling subscriber who desires a trunk call is extended by his local exchange operator over special trunk *record circuits* to recording positions at the trunk exchange. The operators at the recording positions are required merely to enter on a ticket details of the call required, of the calling subscriber's number, etc. The recording operators can therefore be accommodated at tables and the trunk record circuits terminated at these tables on a simple calling equipment with facilities for the operator to associate her telephone with the record circuit. At large trunk centres where at certain times of the day a large number of record operators were necessary, a record distributing position was sometimes installed. This position was substantially similar to a plug-ended B-position of a manual exchange with a number of single plugs and cords connected directly to the record operators' circuits. The record circuits themselves were terminated on lamp calling equipment in the jack field and the distributing operator was required merely to connect any calling record circuit to a free record operator. By means of the distribution position the record traffic could be evenly distributed amongst the available operators and in the less busy periods concentration could be readily effected.

As soon as the record operator had obtained the required details, the calling subscriber was requested to replace his receiver and to await the call. The call ticket was then passed either by hand or by pneumatic tube to a particular trunk position which handled calls on one or two specific routes. The long distance trunk circuits were not multipled, but were terminated on one position only so that the operator on that trunk position had

exclusive control of some four or five circuits. The operator on the delay position arranged the tickets in time order and completed the calls as the trunk lines became free. After establishing the call to the distant subscriber, the trunk operator recalled the originating subscriber and so completed the connexion. Special clocks with a printing mechanism known as *Calculographs* were provided on each trunk position, and the call was timed by the trunk operator inserting the ticket into the mechanism of the clock at the beginning and end of conversation.

It is apparent that, with the delay system, team working between the trunk operators is not practicable. For instance, at some particular time of the day there may be comparatively little traffic on the circuits concentrated on one trunk position, whilst the traffic over another group of circuits on a second trunk position may be very heavy. Moreover, in the event of the trunk circuits being engaged no provision is made for alternative routing of the call.

Demand Trunk Working. With the trunk demand system a subscriber obtains access to the trunk operator either by dialling "0" where the exchange is of the joint trunk type or by dialling "94" (or TRU) when separate trunk and toll working is employed. The calling equipment is multipled throughout the trunk suite and any free operator can answer the call. The operator inserts the answering plug of a convenient free cord circuit into the incoming jack, and ascertains from the subscriber details of his number and of the number required. She then consults the visible index file on her position to determine the correct routing and, for coin-box calls, to ascertain the appropriate fee.

Fig. 544 shows a typical sheet from the visible index file of the Edinburgh trunk exchange. All zone and group centres together with all other exchanges where there is sufficient community of interest are scheduled alphabetically in the file. Details are also given of the call charge index letter which enables the operator to determine the fee from a separate key sheet in the visible index file. Details are also given of the terminal group centre and of the primary route and alternative route to be used in establishing the call. Birkenhead, for example, has the charge index letter M (which at the present time refers to a fee of 3s. 9d. for a 3-min call at the full day rate). The terminal group centre is Liverpool and the primary route is via Liverpool trunk exchange, the originating operator being required to dial "0" to obtain the Liverpool operator. If the Liverpool circuits are engaged, then the alternative route is via the Glasgow demand circuits, and here again the operator must dial "0" to reach the Glasgow incoming switchboard. The Glasgow *demand* route is specifically mentioned in this instance since there is a separate no-delay

BELFAST

Exchange	Index Letter: 5 M. Cir.	DF	NB	Terminal Group Centre	Routing: Primary	Alternative
◆ Belfast	L	L	M	Belfast (Auto)	G(DEM)×O	L×O
Bell (Glasgow)					G/BE×No.	G(ND)×4 No.
---					G(DEM)×BEL No.	N×O
Bellshill					G(ND)×O	BG
Benton	I	K	I	Newcastle (Auto)	N×No.	G(DEM)×O
Bermondsey	P	P	P	London (Auto)	L×BER No.	G(DEM)×O
◆ Berwick-o-T'd	G	H	F	Berwick (Auto)	N/BW	N×O
Biggar					W/LA	G(ND)×O
Bilston	N	N	N	W'hmptn (Auto)	B×21 No.	M×O
Birchflds (B'm)	N	O	N	Bmnghm (Auto)	B×BIR No.	G(DEM)×O
Birgham					CO	KO
Birkdale	M	M	M	Southport (Auto)	---	---
Birkenhead	M	M	M	Liverpool	LV/×O	G(DEM)×O
◆ Birmingham				Birmingham	B×O	G(DEM)×O
◆ Bp. Auckland	K	K	K	Bp. Auckland	N×O	G(DEM)×O
Bishopbriggs					G(ND)×6B	BG
Bishopsgate	P	P	P	London (Auto)	L×BIS No.	G(DEM)×O
◆ Bp's Stortford	P	P	P	Bp's Stortford	L×O	G(DEM)×O
Bish'pt'n (Rfw)					G(ND)×O	BG
Bitton	P	P	P	Bristol	LV/×O	B×O
◆ { Blkbrn (Lan)	M	M	M	Blackbrn (Auto)	M×O	G(DEM)×O
{ Blkbrn Gp.				Blackburn	---	---
Blackf'rd (Prth)					DE/PH	KI×O
Bl'kfriars (M'tr)	M	M	M	M'chester (Auto)	M×BLA No.	G(DEM)×O
Blackh'th (B'm)	N	O	N	Bmnghm (Auto)	B×BLA No.	G(DEM)×O
Blackness					LG	BO
◆ Blackpool	L	M	M	Blackpool	M×O	LV/×O
Blagdon	P	P	P	Bristol	LV/×O	B×O
Blainslie					GL	PB
Blair Atholl					DE/PH	KI×O
Blairgowrie	G	G	G	Dundee	DE	G(DEM)×O
Blanefield					G(ND)×O	BG

BLANEFIELD

FIG. 544. TYPICAL SHEET FROM A VISIBLE INDEX FILE

group of junctions to Glasgow of lower transmission efficiency for group-to-group centre calls. It will be noted that no call charge index letter or terminal group centre is shown for certain exchanges, e.g. Biggar. Such entries refer to exchanges in the toll area of the trunk exchange, and the operator must consult a separate index which gives the different toll charges for the various originating exchanges within the group. The exchange names marked ◆ are themselves terminal group centres and are picked out in the index to enable the operator to determine the routing to any minor exchange not shown in the visible index after she has ascertained the name of the terminal group centre concerned.

It is, of course, impossible to enter in the limited accommodation of the position visible index file details of all exchanges throughout the country. If a call is requested to some exchange which is not included in the file, the trunk operator inquires

from the *route and rate quoting position* the name of the terminal group centre. She can then find the primary and alternative routing to that group centre from her own visible index file.

Having ascertained the routing details, the trunk operator attempts to complete the call first over the primary route, but if all trunks in the primary group are engaged, she attempts to set up the connexion via the scheduled alternative route. If the route connects directly with the terminal group centre she gives to the incoming operator details of the exchange and number required. If, however, there is an intermediate switching point before the terminal group centre can be reached, the operator requests the incoming operator at the intermediate exchange (or exchanges) for the name of the terminal group centre and only gives details of the exchange and number required when the terminal group centre telephonist is reached. The terminal group centre operator is responsible for establishing the call to the number requested, but the control of the connexion is vested entirely in the originating trunk operator. When the called subscriber replies, the controlling operator starts the timing mechanism associated with the cord circuit and she is now free to attend to other calls. At the end of the conversation a clearing signal is received from the originating subscriber, and from the called subscriber when all trunk and junction links are of the automatic signalling type. The clearing signal from the calling subscriber automatically stops the timing mechanism and the operator enters the duration of the call on the ticket which is then dispatched by pneumatic tube to the ticket sorting telephonist.

Suspended Call Procedure. During periods of fairly heavy traffic the operator may not be able to find a circuit either on the primary or the alternative route within a reasonable period. Under normal conditions she continues to search for a free trunk line for a period of 1 min, advising the originating subscriber at ½ min intervals that she is trying to connect him. If at the end of the 1 min period she cannot find a free circuit, she endorses the ticket and dispatches it via the pneumatic tube. She also releases the calling subscriber and indicates to him that the circuits are engaged but that he will be called later. Tickets of this nature are passed by the pneumatic tube distributing officer to a supervisor who in turn passes the tickets in groups of five to a telephonist on a special position known as a *suspend position*. Each suspend position deals with calls for several routes, and the suspend operator continuously attempts to complete the calls in booking time order as the trunk circuits become free. It is apparent that both the normal trunk operators and the suspend position operators are in these circumstances competing for free outlets. There are some difficulties in this connexion, but in general the suspend procedure is preferable to the adoption of full delay working as described below.

Delay Conditions. If the number of suspended calls (as determined by the number of tickets accumulated at the suspend positions) becomes greater than a predetermined figure, the supervisor may decide to introduce full delay working on a particular route. By the operation of a key in the cable turning section a red delay lamp is lighted at the beginning of each multiple appearance of the trunk route. The glowing of this lamp informs each trunk operator that she must not complete any calls over this particular route. At the same time the supervisor determines from the number of waiting calls, and from tables supplied to her, the probable period of delay. Arrangements are made to post up the delay period so that when any call over this particular route is demanded, the trunk operator dealing with the call can advise the calling subscriber of the anticipated delay.

The trunk operator makes out a ticket in the usual way and requests the originating subscriber to replace his receiver. The ticket is passed by the pneumatic tube distributing officer to a special *delay position* which is previously scheduled for the control of this particular route under delay conditions. The delay operator holds the tickets in booking time order and proceeds to dispose of the calls in the most expeditious way. Full delay working differs from the suspend procedure in that the delay operator has exclusive use of all trunk circuits. With full delay working the calls are therefore dealt with in strict chronological order as compared with the somewhat chance completion under suspend conditions. It is apparent that special arrangements must be made when the circuits on a route are of the bothway type. In these circumstances the controlling supervisor who determines that a route shall go into delay working also advises the supervisor at the distant trunk exchange, and the complete group of bothway circuits is split in a prearranged manner so that the delay operator has the use of approximately half the circuits whilst the distant trunk exchange can utilize the remaining circuits for traffic in the opposite direction.

Distant Trunks Engaged. It sometimes happens that although a trunk telephonist can readily find a circuit on her primary or alternative route to some intermediate exchange, congestion may be experienced on some group of trunks or junctions beyond the first trunk link. For example, on a call

to Ballymena (Northern Ireland) the trunk operator at Edinburgh may find a free circuit to Belfast, only to find that the Belfast to Ballymena circuits are repeatedly engaged. It is apparent that repeated efforts of the Edinburgh operator in the hope of reaching Belfast at the time when there are free Ballymena circuits is merely wasteful. In these circumstances the originating trunk operator requests the incoming trunk operator at the most distant point reached to *rebook* the call. The originating operator gives full details of the calling and called parties' numbers which are entered on a special type of ticket by the incoming rebooking operator. The originating exchange operator endorses her own ticket that the call has been rebooked at a certain exchange and the original ticket is now filed against possible inquiries. The originating trunk operator takes no further interest in the call and the calling subscriber is advised

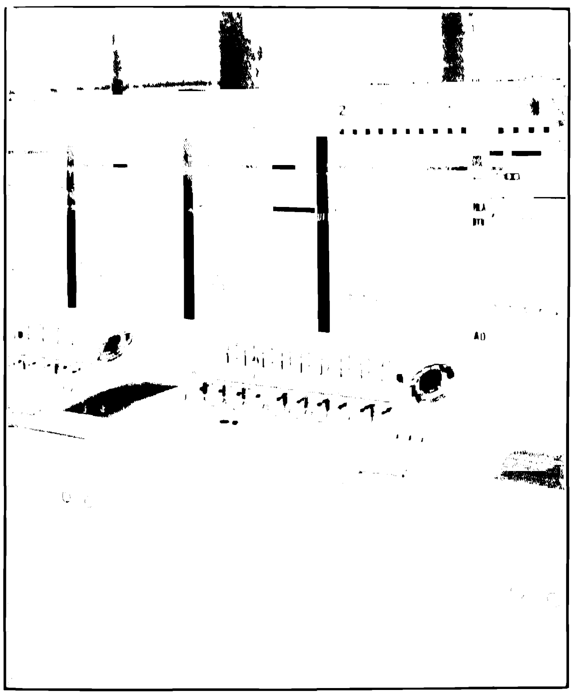


FIG. 545. LOW-TYPE AUTOMANUAL SWITCHBOARD

that he will be called later. At the rebooking exchange the ticket is passed to the appropriate suspend position and the call is established by this operator when free circuits are available. It will be noted that the operator at the rebooking exchange has complete control of the connexion and undertakes the timing of the call.

Switchboard Design—Low-type Sections. Two sizes of switchboard section have been standardized for automanual and trunk exchanges. Both types accommodate keyshelves 27 in. wide and both are designed for sleeve control working. The smaller type is 4 ft $8\frac{1}{2}$ in. high and is provided as one or three position sections. The single position



FIG. 546. FRAMEWORK OF SINGLE POSITION (Low type)

sections are made up in four types known as A, B, C, and D type sections respectively. The four types are identical as regards width and height but differ in respect of the position of the stile strips. Sections A, B, and C assembled together form the equivalent of the three-position seven-panel section. The D type section is a separate two-panel unit and is used only in bends. The panel capacity of the 4 ft $8\frac{1}{2}$ in. section is twenty-six jack and lamp strips exclusive of the space allotted at the bottom of the panel for pigeon holes. One jack space is required for a wide dummy strip at the top of the multiple which acts as a dust cover to the jacks below.

The low-type section has been extensively used for automanual switchboards at minor exchanges, and is illustrated in Fig. 545. Fig. 546 shows the constructional details of a single position section which incorporates a number of recent improvements. The new design is made up as two parts, a universal base section which can be used either

for low- or high-type sections and a top section of the required height. This arrangement, and the use of a bolted instead of a welded framework, facilitates transportation and at the same time permits of future conversion. The switchboard position equipment is mounted on a self-contained panel which can be bench wired to facilitate installation, whilst a number of other changes have been made to promote standardization, to reduce the cost and weight, and to facilitate maintenance.

be adjacent to angle sections. Where the suite grows from left to right and commences with a B or a C type section or ends with an A or a B type section, the incomplete panel at the beginning or end is completed and fully equipped. This is achieved, as shown in Fig. 549, by the provision of an end panel which has accommodation for the incomplete part of the last jack panel.

Figs. 550 and 551 show front and rear views of a typical three-position section of the 6 ft $4\frac{1}{2}$ in.

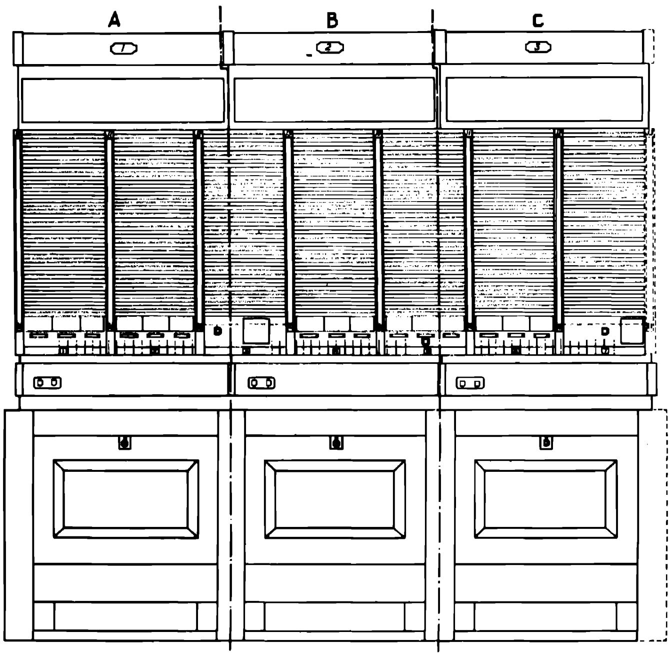


Fig. 547. A, B, and C Type Sections Erected Together

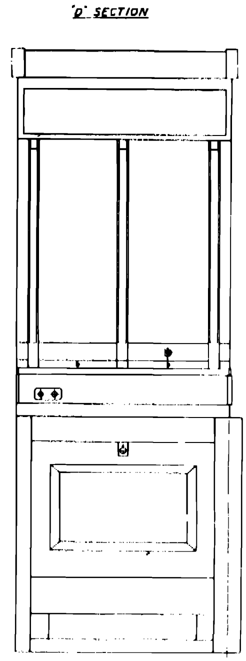


Fig. 548. Panel Arrangement of D-type Section

High-type Sections. The second type of section s 6 ft $4\frac{1}{2}$ in. high and is normally supplied as a three-position seven-panel section. Single-position sections similar to the A, B, C, and D types described above are, however, available for use in bends and to make an odd one or two positions on straight runs where it is impossible to accommodate the usual three-position section. Fig. 547 shows how the A, B, and C type single-position sections can be assembled to form the equivalent of a three-position seven-panel section. At right-angled bends, 30° angle sections, each fitted with a complete panel of answering and outgoing equipment are provided. To avoid unnecessary stretch it is desirable that the D type section (Fig. 548) used in the bends should, wherever possible, be preceded and followed by a complete three-position section or its equivalent. B-type sections should never

type, whilst Fig. 552 gives a cross-section of the same type of switchboard. It will be noted that the constructional details differ from those of the latest design illustrated in Fig. 546. The panel capacity is forty-seven strips, including one which is required for the accommodation of the dust cover. In the 6 ft $4\frac{1}{2}$ in. type section, the normal capacity can, however, be increased to a total of fifty-nine strips by removing the lower cornice. The cables serving the jack field are supported at frequent intervals by steel pins which are inserted into regularly spaced holes in a flat steel bar behind the stile strip. The weight of the cables is supported by chains suspended from the roof of the section which engage with the free ends of the cable pins. This arrangement very considerably facilitates maintenance and provides a cable lay-out which cannot readily be displaced.

Answering Multiple. Except in special circumstances, all incoming circuits to a sleeve control automanual or trunk switchboard are provided with multiple answering equipment. Where it is desired that a call should be answered only at a specified position or group of positions, it is usual to withdraw the calling lamps at the remaining positions. The answering jacks are arranged in strips of twenty with the associated lamp jack immediately above. Generally, a third strip is placed above the lamp jack to accommodate the designation labels, but in certain cases with low-type switchboards where the full capacity of the jack field is required, a system of labelling on the face of the lamp jack strip is employed. The combined lamp cap and designation label is illustrated in Fig. 553. The brass label holder (*c*) plugs into the lamp jack and carries lugs to accommodate a flat metal designation label (*a*). The label contains a slot through which the glow of the calling lamp can be seen. Normally, a translucent piece of celastoid is inserted behind the label to prevent glare but, in cases where there are difficulties of seeing the calling signal from an oblique angle, the celastoid is replaced by an opal glass (*b*) with a bulbous extension which projects through the slot of the label.

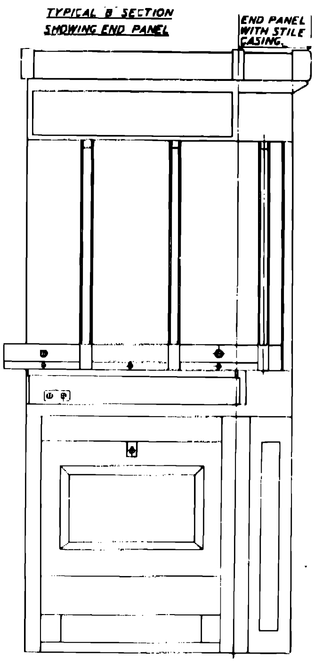


FIG. 549. END PANEL WITH JACK SPACES TO COMPLETE A SUITE ENDING WITH A B-TYPE SECTION

In order to avoid plug congestion, multiple answering equipment is often provided in excess of the initial requirements so that every alternate jack can be used. The spare jacks are absorbed later as the exchange grows and the number of incoming circuits increases.

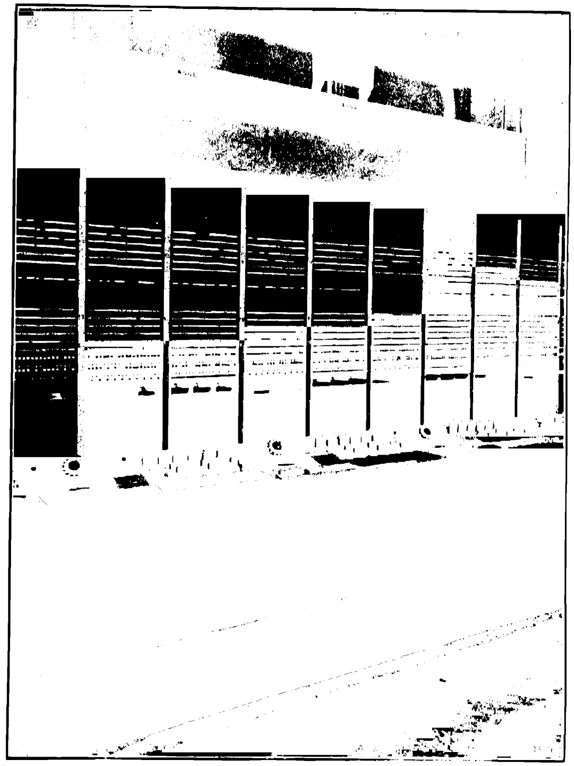


FIG. 550. FRONT VIEW OF TRUNK SWITCHBOARD (with 6 ft. 4½ in. sections)

Six-panel repetition (A0–A5) is the standard arrangement for answering multiples, i.e. each calling lamp is repeated rather less than every three positions. With this rate of repetition, it may not be possible to accommodate the large number of incoming circuits which are required at a big trunk centre. Under these circumstances, a twelve-panel repetition of the answering multiple is adopted. It may so happen, however, that whilst a twelve-panel repetition is necessary at the ultimate date, a six-panel repetition would be more efficient at the outset. The twelve-panel multiple is then converted to a temporary six-panel multiple by commoning at the I.D.F. the jacks on panels A0—A6, A1—A7, etc., to A5—All. As the number of incoming circuits increases, the multiple can be gradually restored

to twelve-panel repetition by disconnecting the commons of individual jack strips or of complete panels.

Multiple Answering Circuit. Fig. 554 shows the detailed circuit arrangements of the lamp circuits and of the power supply. The lamps are of the 6 V type and are normally fed direct from the a.c. mains via a step-down transformer. If the mains should fail, the supply circuit is automatically switched to a 6 V tap on the exchange battery.

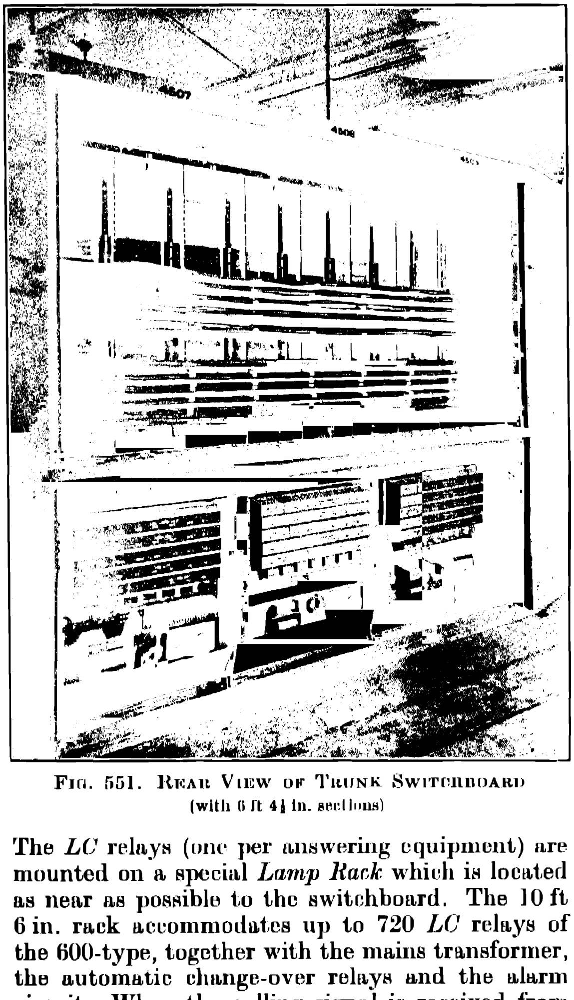


FIG. 551. REAR VIEW OF TRUNK SWITCHBOARD (with 6 ft 4½ in. sections)

The *LC* relays (one per answering equipment) are mounted on a special *Lamp Rack* which is located as near as possible to the switchboard. The 10 ft 6 in. rack accommodates up to 720 *LC* relays of the 600-type, together with the mains transformer, the automatic change-over relays and the alarm circuit. When the calling signal is received from the terminal relay set, relay *LC* operates and at ***LC*1** and ***LC*2** applies an earthed a.c. supply to the parallel connected answering lamps. It will be noted that alternate lamp appearances are fed separately from two supply circuits in order to guard against the failure of an *LC* contact or distribution fuse. Each lamp-strip multiple is served by a 20-wire cable of the ordinary switchboard type. The earth tags of the lamp jacks are commoned together and are connected to main earth feeder cables of 7/·064 gauge at intervals of approximately six positions. Potential drop considerations are of very great importance in the design of the cabling system for multiple answering lamps. The maximum volts drop between the lamp relay rack and the most distant appearance should not exceed 1·5 and, when this is not possible, half the appearances are supplied by a separate

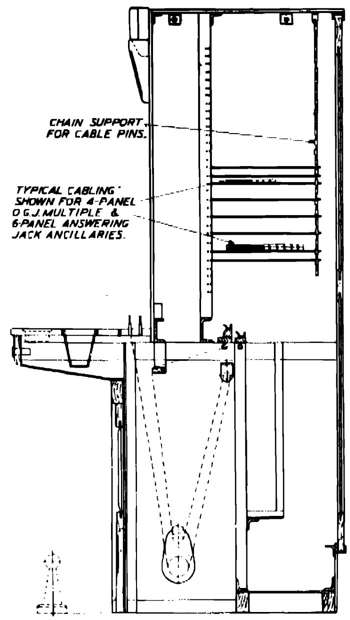


FIG. 552. SECTION OF SLEEVE CONTROL SWITCHBOARD

pair of cables which are commoned to *LC*1 and *LC*2. The loading of the *LC* contacts must also be considered and a limit of ten lamps per contact is applied in practice. When the number of appearances exceeds 20, an additional pair of *LC* contacts is provided.

Relay-*MF* is connected to the output of the mains transformer and, if the mains fail, relays *MF* and *MFA* release and relays *AL* and *CO* operate. ***AL*3** gives an audible alarm whilst ***CO*1** and ***CO*2** (mercury contacts) change over the supply leads to a 6 V tap on the main exchange battery. The main alarm can be cleared by the operation of the "Receiving attention" key and when the mains supply is re-established the circuit can be restored to normal by the operation of the "Reset" key. The automatic change-over can be tested at any time by releasing the tumbler switch in the *MF* relay circuit.

Outgoing Multiple. The outgoing multiple is normally on a four-panel repetition basis (JO—J3) and is arranged in three sections in the following order starting from the top:

(*a*) *The service multiple* for miscellaneous lines of not very great importance. The service multiple has not, in the past, been provided with Free Line Signals, but will be so equipped in the future.

(*b*) *The auto. multiple* (with F.L.S.) for the outgoing dialling circuits to exchanges in the automatic area.

(*c*) *The junction and trunk multiple* (with F.L.S.) for the junction, toll and trunk circuits (arranged in alphabetical order).

Under the new arrangements, all the outgoing multiple is identical from an equipment aspect, and hence the limits of the separate sections can be adjusted when required to meet the circuit growth. For example, in certain circumstances it may be preferable initially to locate the auto. multiple in the space ultimately required for the junction and trunk multiple if by so doing operating is facilitated by the shorter vertical reach. The outgoing multiple is arranged in strips of twenty jacks with the F.L.S. lamp-strip immediately above the line jacks. Where F.L.S. is not provided initially, a designation strip is provided in the lamp jack space and it is therefore possible to add F.L.S. at a later date without involving a rearrangement of the multiple.

Where F.L.S. is provided, the circuit designation labels are accommodated on the face of the lamp

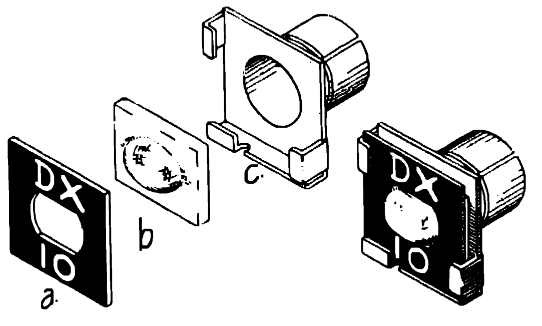


FIG. 553. COMBINED LAMP CAP AND LABEL

jack. The label holder is in the form of a channel section strip (Fig. 555) which extends the full length of the lamp jack and is secured to the latter by several small screws. The label itself is of thin brass engraved with the circuit designations (*c*) and is slipped into the end of the holder. An amber-coloured celastoid strip (*b*) is inserted behind the label to prevent glare. The label gives the name of the route and the individual numbers of the circuits, but it is also designed to give certain other information to the operator. For example, the colour

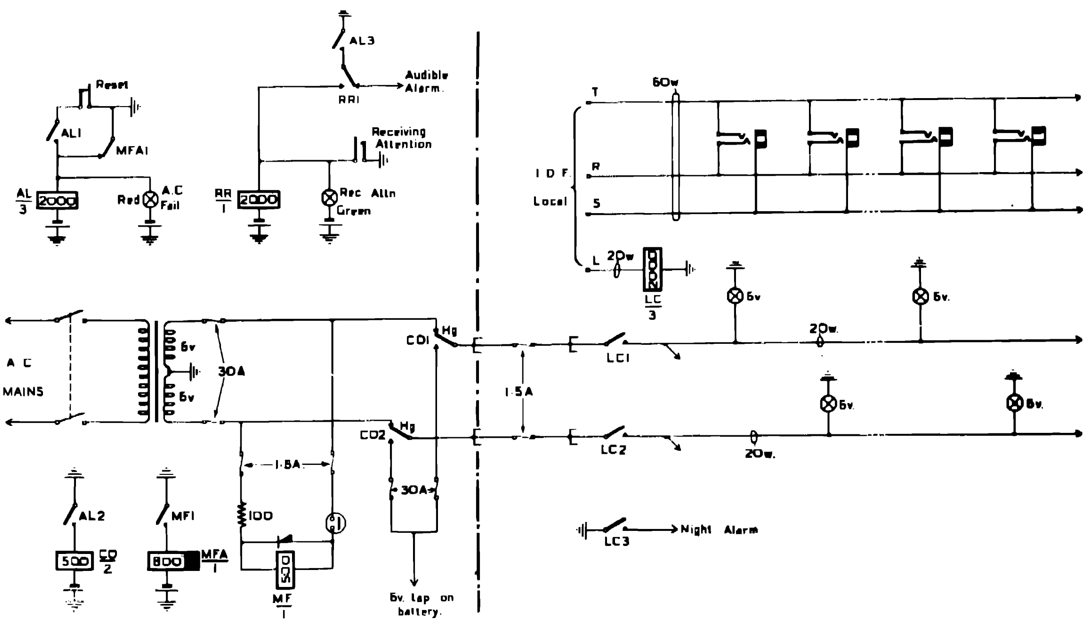


FIG. 554. MULTIPLE ANSWERING CIRCUIT

of the label background indicates the chargeable distance of the circuit, viz.:

Background	Engraving	Type of Circuit
White	Black	under 5 miles
Green	Black	5 to 7½ miles
Orange	Black	7½ to 15 miles
Yellow	Black	over 15 miles
Blue	White	zone-group demand circuits

The F.L.S. label also shows the method of signalling (e.g. ring, dial, etc.) in red characters following the name of the route. A further facility is the priority marking of long distance circuits which are worked on a bothway basis. The exchange which takes priority on any particular circuit is indicated by brackets round the circuit number on the F.L.S. label. (See Fig. 555.) Thus, if operators enter both ends of the circuit at the same time, the operator at the exchange with the bracketed number takes preference.

There are numerous other operating aids and variations of the above in special circumstances, but it is not possible to deal with this subject comprehensively in this volume.

F.L.S. Circuit. The arrangements of the free line signalling circuit (Fig. 556) are generally similar to the multiple answering equipment with the exception that change-over contacts are now provided to light the F.L.S. lamps of the next circuit in a group when one circuit is taken into use. When all circuits in a group are free, 6 V a.c. is applied to the F.L.S. lamps of the first circuit via *VC*1 and *VC*2. It will be noted that separate feeds are provided for alternate multiple appearances as in the multiple answering circuit. Relay *VC* operates

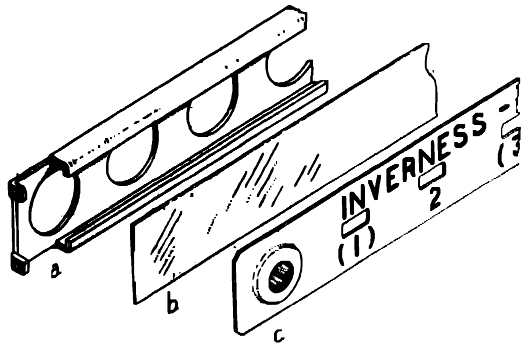


FIG. 555. F.L.S. DESIGNATION STRIP

to the earth on the *K*-wire when the first circuit is taken into use and **VC1** and **VC2** switch the a.c. supply to the second circuit in the group. When the second circuit is engaged, the *VC* contacts of that circuit extend the a.c. supply to the third circuit and so on. If an intermediate line becomes free, the F.L.S. restores to indicate the first free line in the group—even although later circuits may still be engaged. On a mains failure, *SF* and *SFA* release, and *AL* operates to give an audible alarm at *AL2*. No facilities are provided for an automatic

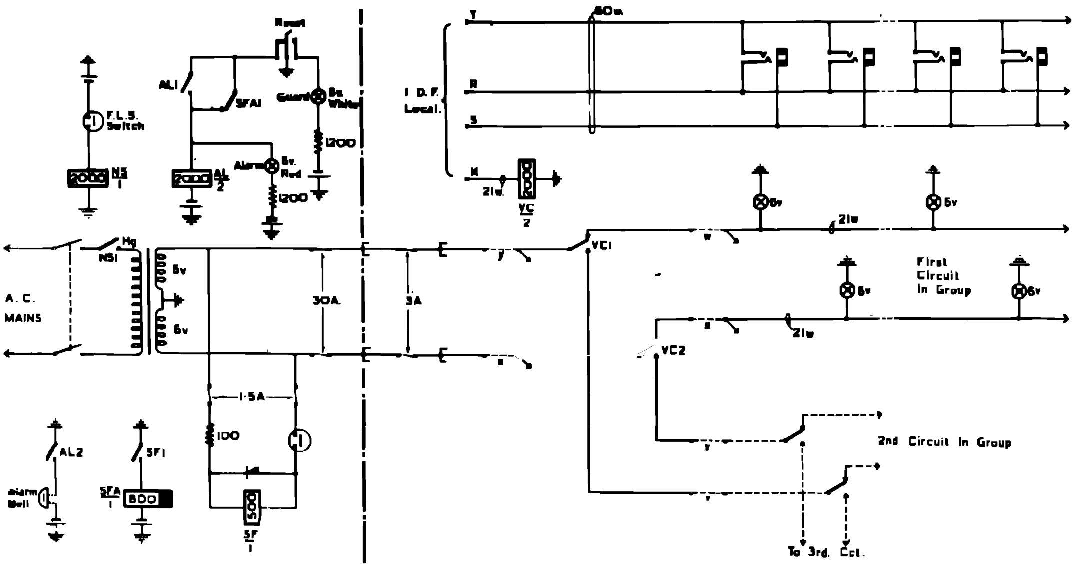


FIG. 556. FREE LINE SIGNAL CIRCUIT

change-over to the battery and the operator must resort to "click" testing during any period of failure. An F.L.S. switch is provided on the cable turning section to enable the supervisor to cut off the F.L.S. during periods of light traffic, e.g. during the night period. Under these conditions the alarm system is disconnected at the reset key contacts and a white guard lamp glows until the reset key is restored.

Facilities must be provided to rearrange the junction groups to meet changing traffic conditions. The *VC* contacts are therefore wired to connexion strips on the F.L.S. relay rack in such a way that they can be grouped together as required by inserting short bare tinned copper straps (*w*, *x*, *y*, and *z*, Fig. 556) between adjacent tags. The extensive connexion strip space required limits the capacity of the 10 ft 6 in. F.L.S. relay rack to 360 circuits (Fig. 557).

Timing Equipment. Long distance trunk circuits are expensive to provide and the call charges are correspondingly heavy. It is important, therefore, in any system that calls over the longer circuits should be accurately timed. The timing device is started when the controlling operator has verified that the call has been satisfactorily established, and is stopped when the calling subscriber (who pays for the call) replaces his receiver at the end of conversation. The first design of automatic timing mechanism utilized a standard 25-point uniselector and is known as the *Chargeable Time Indicator*. A number of cord circuits on each position are provided with a double throw key in addition to the normal speaking and ringing key. A common strip of eighteen lamps is provided in the jack field opposite each operator's position, and is fitted with a yellow stencilled translucent strip bearing the numbers 1 to 18 minutes. When a long distance call is satisfactorily established the operator throws the time check key of the cord circuit to the "start" position. A circuit is now completed for the uniselector mechanism which is stepped at 12 sec intervals from a master clock. At the end of the conversation the clearing signal from the calling subscriber automatically stops the drive circuit of the uniselector and when the operator moves the C.T.I. key to the "stop time and display" position, the number of minutes is indicated on the common display strip. There are two types of chargeable time indicator equipment. One displays calls of up to 9 min, the other catering for calls of 18 min duration. The uniselector circuit in both cases is arranged to give three "pips" of 900 c/s tone to the subscribers just prior to the end of each 3 min period. A time check lamp associated with the cord circuit also glows just prior to the end of each 3 min period to warn the operator that on coin-box calls an additional fee is required. If the call continues to the limit of the timing equipment (i.e. 9 or 18 min) the time check lamp flickers continuously to warn the operator that the mechanism must be reset.

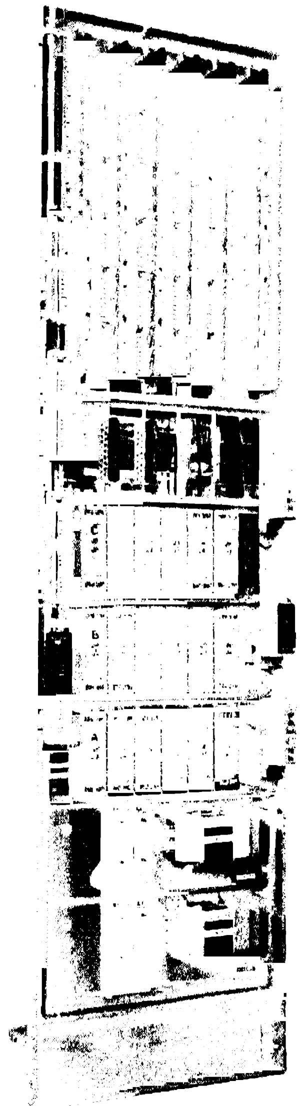


Fig. 557. F.L.S. Lamp Relay Rack

Subsequent to the introduction of the uniselector type chargeable time indicators, a more compact and cheaper timing device known as the *Chargeable Time Clock* was introduced. The chargeable time clock is an electrical timing device of the Veeder type. It is fitted with a combined two-position rotary key (black) and a mechanical resetting plunger key (red). It can be mounted (Fig. 558) together with an ordinary speaking and ringing key on a $4\frac{1}{4}$ in. × $1\frac{1}{16}$ in. key-plate. The clock is driven by pulses at 6 sec intervals from a master clock and gives all the facilities provided by the chargeable time indicator except that the maximum displayed time is 9 min. A red time check lamp associated with the chargeable time clock gives a visual signal to the operator at the end of each 3 min period, and a continuous flicker at the end of 9 min. The mechanism is, as before, stopped by the clearing signal from the calling subscriber.

Time Check Circuit. Fig. 559 shows the connexions of a chargeable time clock at a sleeve control exchange. When the start key is operated a 6-sec earth pulse is applied via *SP*3 and ***ST*1** to the *SY* relay. So long as the calling subscriber is on the line ***L*1** is operated, and the resistance of the sleeve circuit in the line termination is 5085 Ω. Under these conditions the potential on the battery side of relay *SY* is substantially 50 V negative. *SY* therefore operates to each earth pulse and at ***SY*1** completes the operating circuit of the clock magnet via contacts ***ST*3**. The clock mechanism contains two cams. The first is rotated one-tenth of a revolution at each operation of the driving magnet, i.e. it makes one complete revolution in 1 min. The second cam makes one step for each complete revolution of the first cam, i.e. it makes one complete revolution in 10 min. In the normal position of the mechanism, the index wheels associated with the two cams display the digits 9.9. On receipt of the first 6-sec pulse, contacts 1 and 4 open. This condition is maintained for the first eight steps of the tenth-minute cam, but on receipt of the ninth pulse, contacts 4 and 5 make. The time check circuit is, however, disconnected at contacts 2 until the ninth pulse in the third minute is received, i.e. after the clock has been in operation from 2 min 48 sec to 2 min 54 sec (depending upon the point in the 6-sec pulse period at which the clock is started). Contact springs 2, 4, and 5 are now operated and earth from ***ST*2** is applied to the time check lamp. Contacts 4 remain closed for the ninth and tenth steps of the tenth-min cam and so maintain the glow on the time check lamp for a period of 12 sec at the end of the third minute. At the same time the operation of contact springs 5 at the ninth step of the tenth-minute cam applies earth from ***ST*2** to the *PP* relay via contact ***PS*1**. Relay *PS* receives three short pulses of earth from the common equipment each 6 sec, and hence the *PP* relay receives three short operations during the 6-sec period whilst contact springs 5 are closed. ***PP*1** and ***PP*2** apply three "pips" of 900 c/s tone to the calling subscriber.

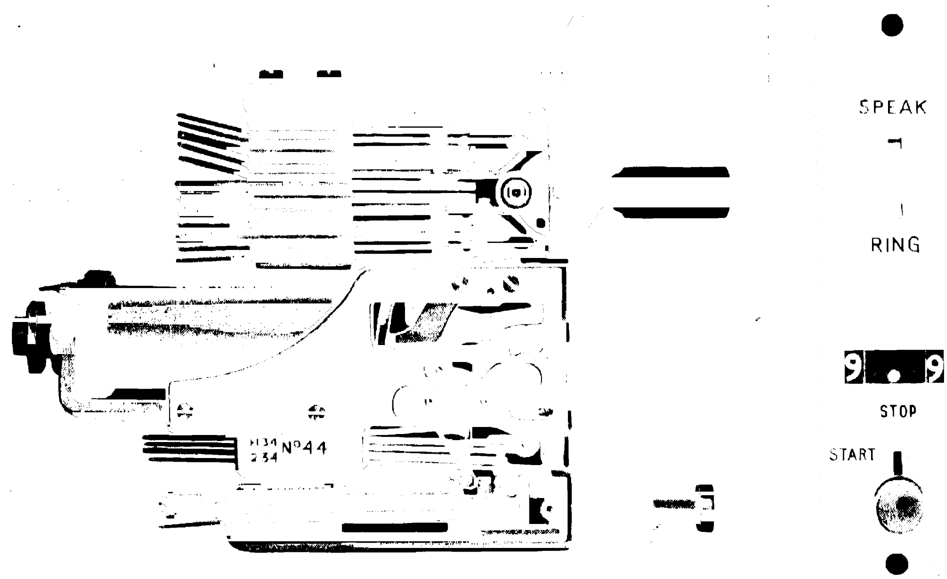


Fig. 558. Chargeable Time Clock

When the calling subscriber replaces his receiver, relay *L* releases and at *L*1 applies an 85 Ω earth to the sleeve conductor. This earth effectively shunts out the battery supply to the *SY* relay so that no further pulses are given to the clock driving magnet. In due course the restoration of the start key and the depression of the re-set key restore the mechanism to normal. If the call is still in

progress at the end of 9 min, the minute cam allows contacts 1 to close, thereby extending earth from ***ST2*** to operate relay *SP* in series with the time check lamp when contacts 3 close at the next step of the tenth-min cam. *SP* locks to ***SP1X***, and ***SP2*** applies continuous flicker earth (0·2 sec on, 0·2 sec off) to the time check lamp. ***SP3*** disconnects the circuit of relay *SY* to prevent further stepping.

Keyshelf Lay-out. Fig. 560 shows a typical

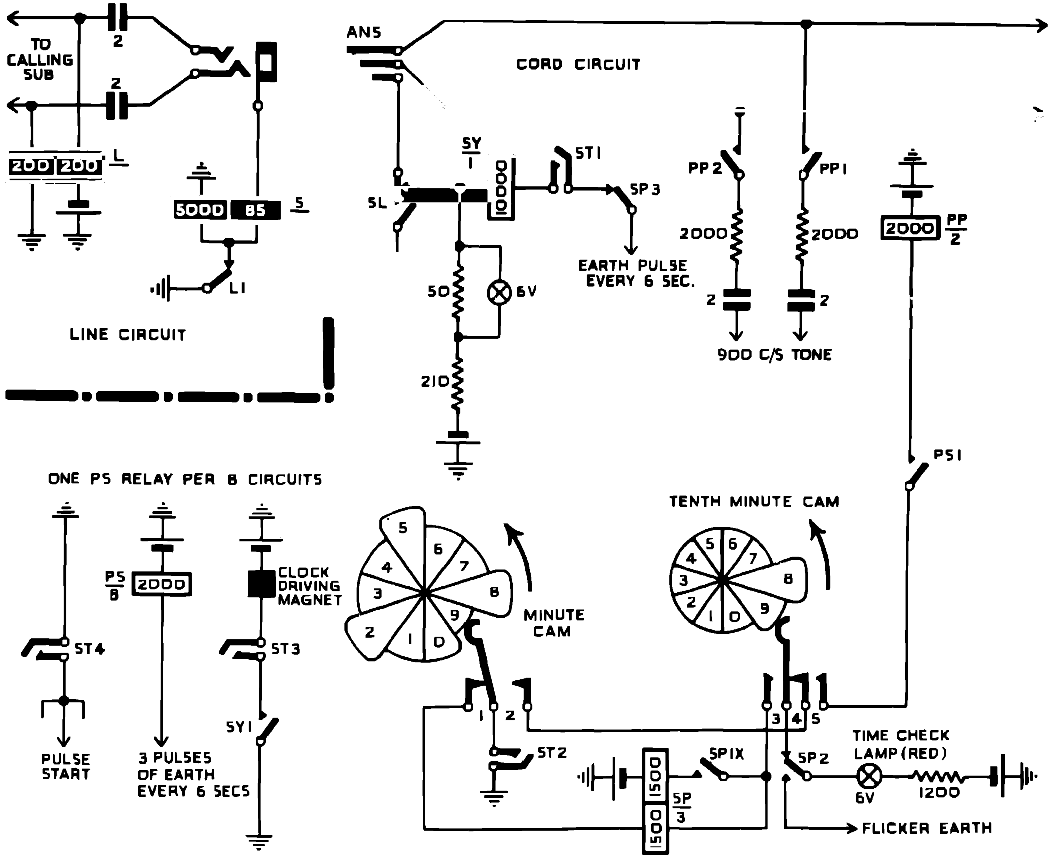


FIG. 559. CALL TIMING CIRCUIT WITH CHARGEABLE TIME CLOCK

lay-out of the keyshelf at a trunk demand position. The plugshelf is drilled for a maximum of seventeen pairs of cords, but the position circuit common keys on the right of the keyshelf limit the number of cord circuits on trunk demand positions to fifteen. The full seventeen pairs of cords can, however, be provided on jack-ended B-positions where the number of common keys is less. The keyshelf illustrated applies to exchanges where chargeable time indicators are fitted. When chargeable time clocks are installed, the positions of the timing and speaking keys are reversed. A transparent bulletin cover provides a convenient writing space for the operator and a place for miscellaneous instructions. The ticket clips for each cord circuit equipped with timing facilities will be noted, as also will the visible index file referred to earlier in this chapter. The posts at the extreme left of the plugshelf provide accommodation for marker rings which are slipped over the handle of the speaking key, as a reminder to the operator, on calls of a special nature (e.g. calls on which she has to collect a fee).

Miscellaneous Switchboard Circuits. In addition to the normal junctions, trunks, assistance circuits, etc., which appear in the incoming and outgoing multiple of the switchboard, there are a number of miscellaneous circuits. Of these, the following are perhaps the more important:

Delay Position Transfer Circuits to enable a demand or an incoming operator to transfer a

caller to a particular delay position. The outgoing end of these circuits appears in the outgoing multiple but the incoming termination is lamped only on the delay position concerned.

Transfer Circuits from Incoming to Joint Positions are required for record purposes in certain circumstances when outlying exchanges are not provided with dialling facilities to the Joint Trunk suite.

Instruction Circuits are provided on all large switchboards to enable the supervisor to "broadcast" instructions to all operators. On receipt of a calling signal on a special red lamp (*IC*) in the keyshelf, each operator enters the instruction circuit by depressing a plunger key.

Engaged Tone Circuits are provided on each position to enable the operator to connect busy conditions to an incoming junction.

Cord Test Circuits are provided for the daily routine of the switchboard cords.

Section Supervisors' Circuits are usually provided on the basis of one circuit per nine positions. The circuit appears in the outgoing multiple and is terminated on an instrument jack on the centre position of each group of nine positions. The calling lamp is fitted either in the cornice of low-type switchboards or at the top of the jack field in the 6 ft 4½ in. sections.

Call Supervisors' Circuits consist of a key and lamp on each position and an associated buzzer (per nine positions) to obtain the attention of the section supervisor.

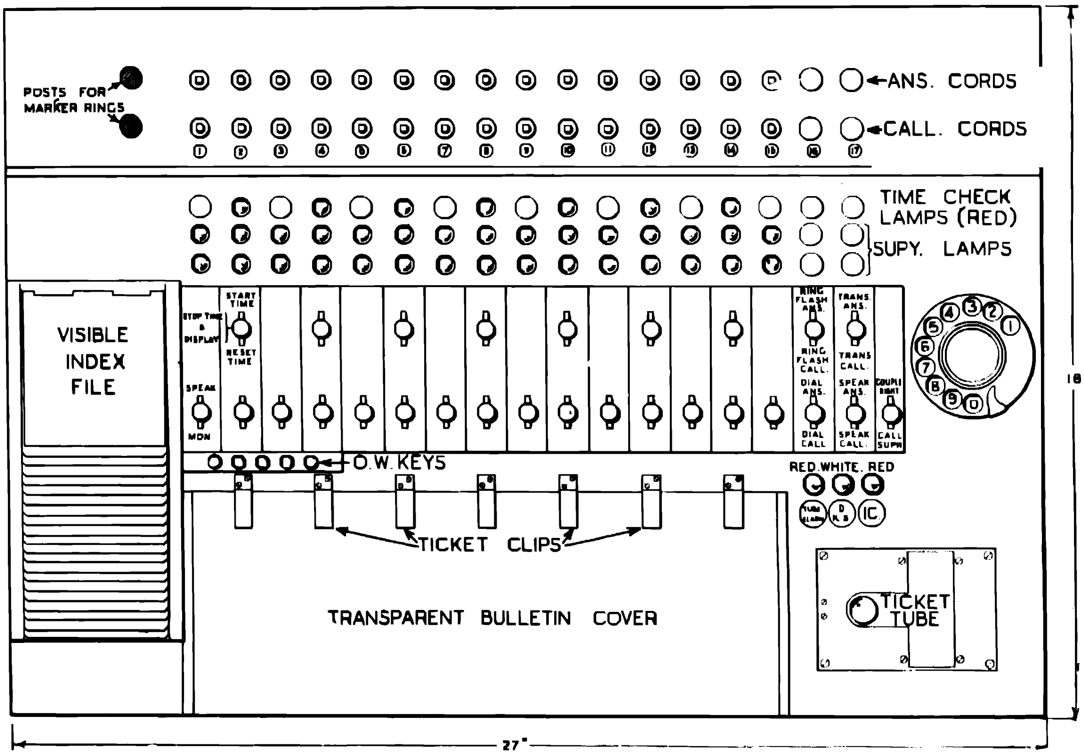


FIG. 560. KEYSHELF LAY-OUT OF TRUNK DEMAND POSITION

Trunk Offering Circuits are provided at automanual switchboards to enable an operator to offer a long distance trunk call to a subscriber engaged on a local call. These circuits are also used for the verification of calling subscribers' numbers.

Special Faults Circuits in the outgoing multiple give access to special telephones in the automatic equipment room. They are used for reporting fault conditions of an urgent nature to the engineering staff.

Monitors' and Supervisors' Desks. A monitor's desk is usually installed at all except the smallest automanual and trunk exchanges. Where a monitor's desk cannot be justified, a position on the main switchboard is set aside as an inquiry position. The standard monitor's desk is made up

of two-position sections with an incoming and outgoing multiple and with cord circuits of the sleeve control type. In a large exchange portions of the monitor's desk are usually reserved for specific types of inquiry e.g. "91" positions, route and rate quoting positions, directory inquiry positions, etc. In some cases arrangements are made to close down the monitor's desk during the night period and to concentrate the inquiry traffic on the main suite. The monitor's desk is usually provided with on the supervisor's desk and can be associated with any of the circuits in the jack field by means of a single plug and switching key.

Switchroom Lay-out. The lay-out of an automanual or trunk switchroom is substantially the same as that of a large C.B. manual exchange (see Chapter XVI). The order of positions depends somewhat on the size and type of exchange. In small exchanges where separate incoming and monitors positions are not justified a single suite



Fig. 561. Corner of a Large Trunk Exchange

listening lines to every operator's telephone circuit. The listening lines are jack-ended circuits and are usually concentrated on the first one or two positions of the monitor's desk. The insertion of a plug into any listening jack operates a switching relay which connects the listening line to the operator's position circuit.

In addition to the monitor's desk, desks are also provided for the exchange supervisors. The supervisor's desk has a small jack field of some sixteen strips to accommodate various incoming and outgoing circuits together with the listening lines to the monitor's desk positions and a duplicate set of listening lines to the switchboard positions. An ordinary H.M.T. type telephone is provided

is installed with the positions in the following order:

Inquiry position;

Three joint trunk or toll positions;

Combined delay and joint trunk positions;

Remainder of joint trunk and toll positions.

Where a monitor's desk is provided the positions of the main suite are arranged in a similar order, excluding of course the inquiry position. When the exchange is sufficiently large to justify separate incoming positions they are placed at the beginning of the suite or, in the largest exchanges, as a separate suite. The positions in each suite are numbered

consecutively from the non-growing end. Where only one suite is provided, the positions are numbered 1, 2, 3, etc., but where two or three suites are provided each suite is numbered in a separate series, e.g. 101, 102, etc., 201, 202, etc., 301, 302, etc. The panels on each separate suite are numbered from "1" onwards. It is not usual to number the switchboard sections.

In future the automanual switchroom will be installed one floor below the top floor of the building, the top floor being reserved for welfare accommodation. The switchroom should if possible be placed on the side of the building which gives the best natural lighting and the maximum freedom from external noise. To obtain the necessary volume of air (400 cu. ft per person) it is usual to provide a minimum switchroom height of 12 ft 6 in. Maintenance requirements necessitate a clear distance of 3 ft minimum between the back of the switchboard and the walls, whilst a minimum 2 ft chair space plus a gangway of 5 ft minimum is required between suites.

Fig. 561 gives a general view of a corner of a large trunk exchange. The lay-out in this particular case is somewhat unusual due to the 1 shape of the switchroom. The non-standard re-entrant angle sections will be noted. A supervisor's desk is shown in the right-centre of the illustration whilst the island suite in the bottom left-hand corner is used for long distance directory inquiries.

Pneumatic Tubes. Pneumatic tubes are provided at all large trunk exchanges for the rapid transmission of call tickets to and from operators. The demand operator, after a call is terminated, completes the details of the call on a standard ticket which is then sent by pneumatic tube to a *Ticket Filing Position* (T.F.P.). If, for any reason, it is not possible to complete a call on demand, then the demand operator partially completes the ticket and dispatches it to the *Pneumatic Distribution Position* (P.D.P.) where a tube operator retransmits the ticket to the appropriate suspend or delay position. The ticket is of heavy weight paper some 5 in. by $2\frac{5}{8}$ in., the end being bent up to form a sail about $\frac{5}{16}$ in. high. The ticket is inserted directly (without the use of carriers) into the pneumatic tube with the sail at the back. The tubes are of brass and are rectangular in section ($2\frac{3}{4}$ in. by $\frac{3}{8}$ in.) with slightly ribbed walls in order to reduce frictional losses. The general arrangements of the pneumatic tube system are shown diagrammatically in Fig. 562.

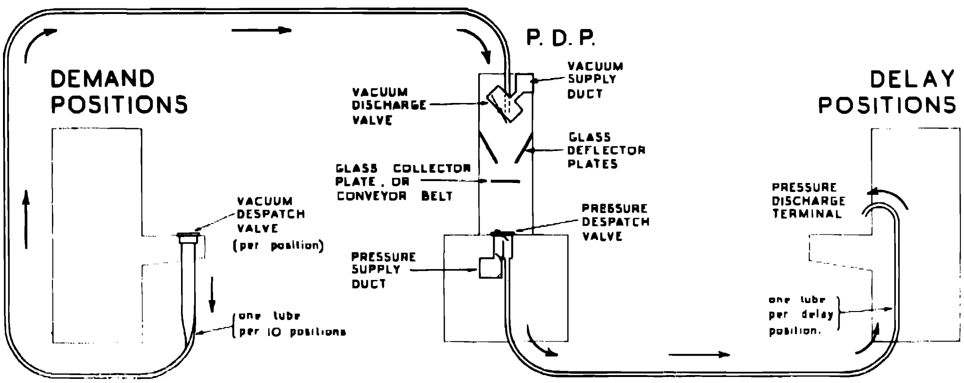


FIG. 562. GENERAL ARRANGEMENTS OF PNEUMATIC TUBE SYSTEM (Diagrammatic)

Vacuum Tubes. The outgoing tubes from the demand positions are of the vacuum type and run horizontally under the front portion of the keyshelf. A dispatch valve is provided per position and as many as ten positions can be served by one tube. The dispatch valve (Fig. 563) is provided with a hinged door which normally makes close contact with its seating. It is important to maintain an effective air seal at this point in order to prevent loss of vacuum to the remaining dispatch valves on the same tube. The valve is opened for the insertion of a ticket by pressure on the button, whilst a spring control is provided to hold the door in its open position and to ensure that it closes properly when released by hand. At the pneumatic distributing position or ticket filing position the incoming tubes from the demand positions are terminated on vacuum discharge valves of the McGregor type (Fig. 564). The discharge valve is entirely automatic in action and consists essentially of a door which is pivoted about its centre line and designed so that it is practically balanced as regards the forces exerted by the vacuum and gravity. It is just sufficiently out of balance to

remain closed normally but to be opened by the impact of tickets which are led through the valve by means of a guide tube. It should be noted that the door has to be in a state of dynamic as well as static balance so that it will close satisfactorily

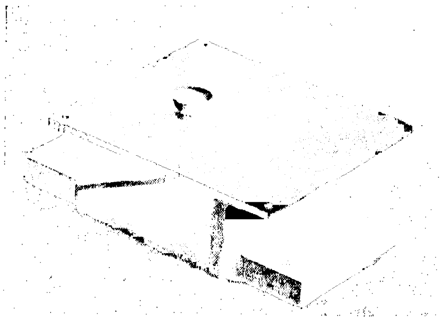


FIG. 563. VACUUM TUBE DISPATCH VALVE

after the discharge of a ticket. Under these conditions the inrush of air on the partially opened door is controlled by a series of holes which form a variable by-pass, depending upon the extent of the opening. After ejection from the vacuum discharge valve, the tickets pass through glass deflector plates to a shelf within convenient reach of the tube operator, or on to a band conveyer.

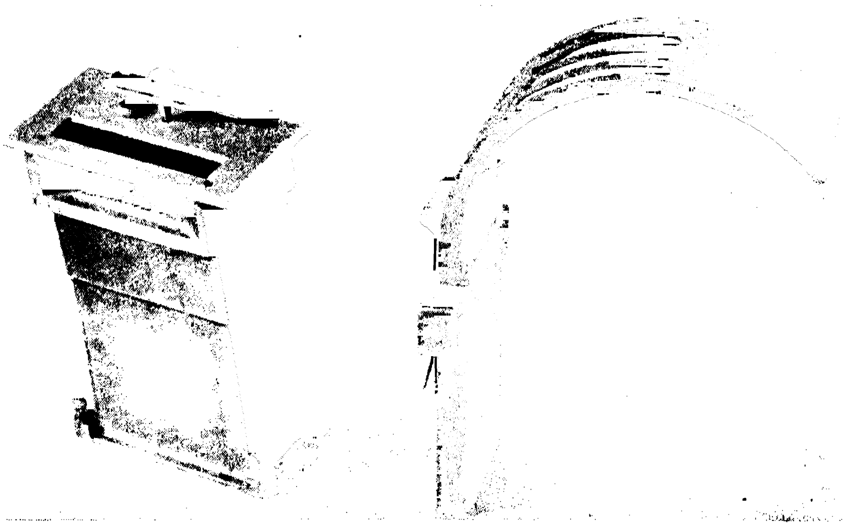


FIG. 565. DISPATCH VALVE AND DISCHARGE TERMINAL OF PRESSURE TUBE

Pressure Tubes. The tubes between the P.D.P. and the delay positions are worked on a pressure system. Each tube has only one dispatch and one delivery valve. The dispatch valves are grouped together on a table either immediately below the vacuum discharge valves or at a separate position. The left-hand portion of Fig. 565 shows the standard form of dispatch valve. Since the tubes are worked on a pressure system, it is impossible

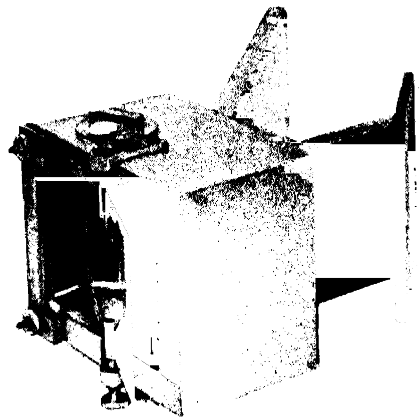


FIG. 564. VACUUM TUBE DISCHARGE VALVE

to insert tickets directly into the tubes without some form of air lock. The pressure dispatch valve is so arranged that the air pressure is not applied to the tube until a button on the valve is depressed after the insertion of a ticket. The depression of the button opens a valve connecting with the air pressure duct, and the admission of air under pressure causes a hinged flap to close the ticket

entry slot and thereby prevent the loss of pressure through this slot. After the depression of the plunger, the valve connecting the tube with the main pressure duct is held open by means of an electromagnet.

The pressure discharge terminal is merely the open end of the pressure tube. It is accommodated in the lower portion of the jack field on the delay position and is so arranged that the ticket is ejected downwards on to the keyshelf (Fig. 565, right-hand portion). A trigger contact is provided at the discharge terminal so that when the ticket passes this point it breaks the circuit of the electromagnet which is holding open the air pressure supply valve to the tube. When the ticket is discharged, therefore, the trigger contact operates and, by releasing the electromagnet on the pressure dispatch valve, automatically shuts off the air supply to the tube. By this arrangement there is no air flow (which would produce uncomfortable draughts to the operators) except when a ticket is in transit. The curved guide of the discharge terminal is also provided with slots so that when the tube is in use, the air escapes into the switchboard and away from the delay position operator.

Alarms. Alarms are provided on the tube system to indicate stoppages or other failures. On the vacuum tubes between the demand positions and the P.D.P., float contactors consisting of a light aluminium vane are arranged to close contacts if the air flow is reduced below a critical value due to a stoppage. This system cannot, of course, be adopted on the intermittently operated pressure tubes to the delay positions. For these tubes, the depression of the plunger on the dispatch valve is arranged to light a lamp which glows until the ticket is discharged. A permanent glow on any dispatch valve therefore indicates a stoppage. It is important that great care should be taken in the installation of the tubes to avoid sharp bends or other irregularities which would check the progress of a ticket.

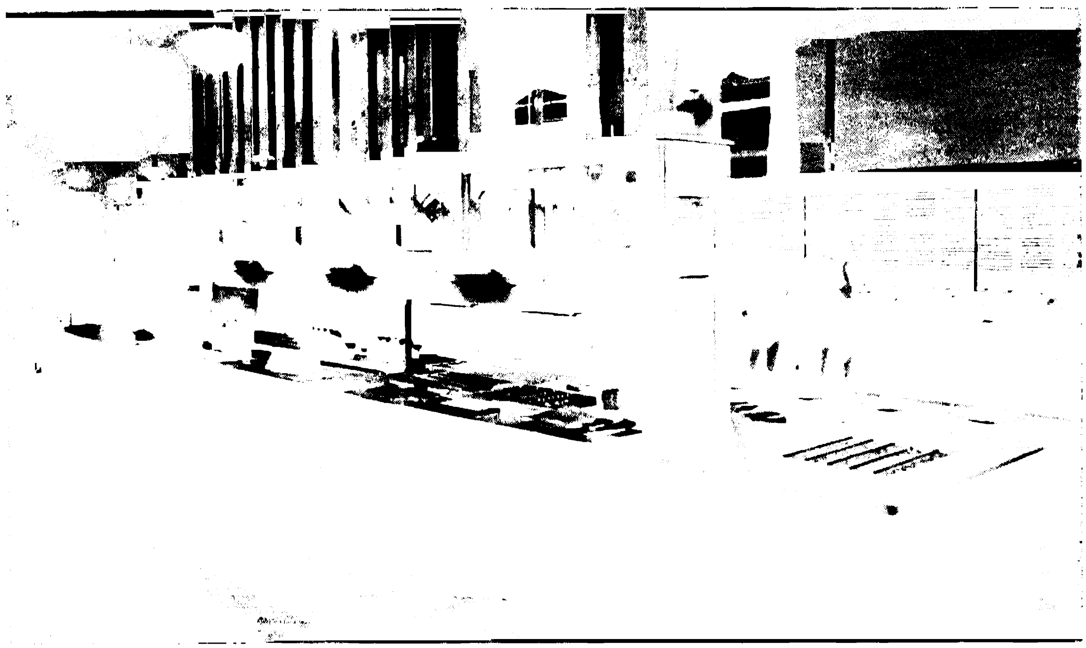


FIG. 566. COMBINED PNEUMATIC DISTRIBUTION AND FILING SUITE

Pneumatic Distribution and Filing Positions. Various arrangements of the pneumatic distribution and filing positions have been adopted in the past. In the earlier installations separate dispatch valves were provided on the demand positions for the disposal of completed and incompleted tickets. The outgoing valve for completed tickets was located in the normal keyshelf position, whilst the outgoing vacuum valve for the tickets ultimately destined for delay positions was accommodated in the lower part of the jack field. At the distributing point, the discharge valves for the completed tickets were placed over the filing operators' positions, whilst the incoming valves

for the incompleted call tickets were arranged above the dispatch valves to the delay positions. By this arrangement the ticket filing and ticket distributing positions were separate.

In other cases all the vacuum tube discharge valves are concentrated over the centre portion of the tube suite and a band conveyer is provided to transmit the tickets either to a filing position or to a separate distribution position.

The future standard Post Office combined unit illustrated in Fig. 566 consists of ten operators' positions (five on each side of the suite) and has accommodation for some twenty vacuum discharge valves. The tickets, after ejection from the valve, fall on to a high-speed conveyer band which delivers all tickets to the two end operators who are concerned solely with placing the tickets all face upwards with the sails in one direction and arranging the tickets in small bundles. The bundles of tickets are placed on a slow moving band conveyer (80 ft/min) which passes a team of four primary sorting operators. The sorting operators remove the bundles of faced tickets from the conveyer band and file all completed tickets in a suitable partitioned tray. Incompleted tickets are extracted and are inserted on a small V-band conveyer which terminates in a trough in front of the dispatch operator. The dispatch operators, on receiving incompleted tickets, distribute them to the delay positions via the outgoing pressure valves which are arranged horizontally in front of the operators.

Route Delay Indicators. When a long distance route is switched to work on a delay basis, it is necessary to provide means whereby the trunk demand operators can advise callers of the approximate delay period on the route. At small exchanges delay posting boards are provided at convenient points in the switchroom and arrangements are made to affix suitable cards to the boards to indicate the approximate delay on each route. As the duration of the delay varies, so the cards are changed accordingly. This method, while quite satisfactory for small and medium sized exchanges, becomes impracticable at large trunk centres on account of the work involved in changing the delay postings.

At larger exchanges an electrical indicator is provided on each position of the switchboard. The spare jack below the delay lamp at the commencement of each trunk route is wired to a key in the cable turning section. The first cord circuit of the position is modified to provide a single delay plug so that when the plug is inserted in the delay jack one or more of the keyshelf supervisory lamps associated with the delay plug lights. The plunger keys on the cable turning section are arranged to provide electrical conditions on the tip, ring and sleeve of the jack to give the following combinations:

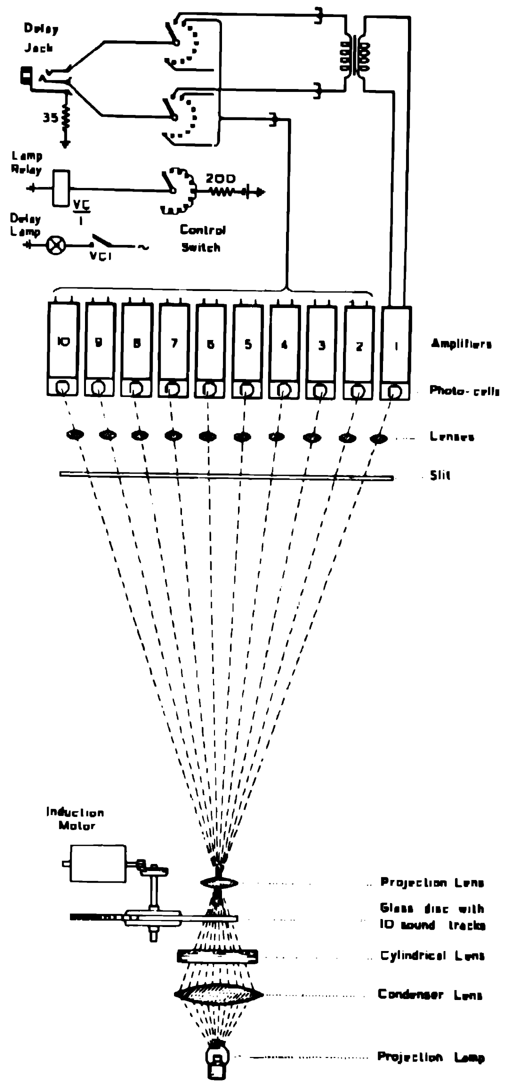


FIG. 567. GENERAL ARRANGEMENTS OF DELAY ANNOUNCING MACHINE

White lamp . .	Up to 30 min delay.
Green lamp . .	,, ,, 45 ,, ,,
Red lamp . . .	,, ,, 60 ,, ,,
White and Red lamps together . . .	,, ,, 90 ,, ,,
White, Green and Red lamps together .	More than 90 min delay.

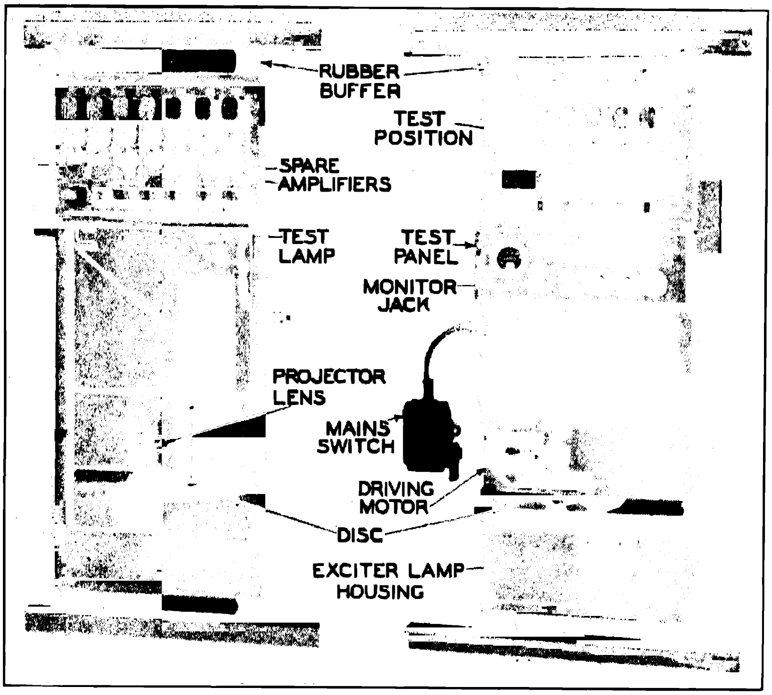


FIG. 568. DELAY ANNOUNCING EQUIPMENT RACK

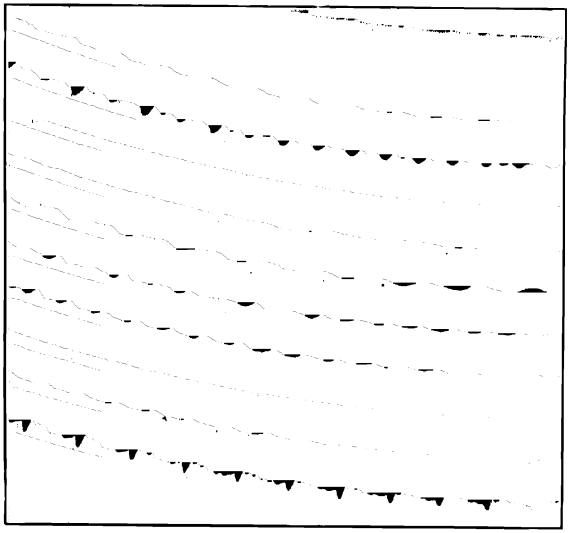


FIG. 569. PORTION OF THE SOUND TRACKS ON DELAY ANNOUNCING DISC

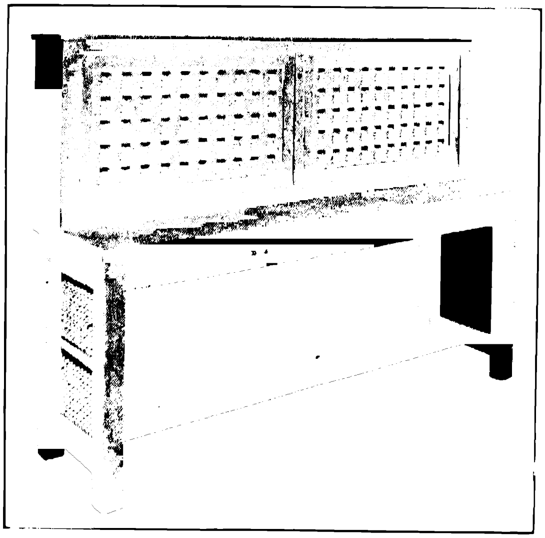


FIG. 570. MASTER CONTROL PANEL (*P.O.E.E.J.*)

The delay keys on the cable turning section are of the plunger type and are provided with lamps so that the delay posting on any particular route is readily visible to the supervisor who is in charge of the delay postings.

When the visual lamp delay indicator equipment does not give the required information the demand operator obtains particulars verbally from an inquiry position set aside for this purpose.

Delay Announcing Equipment. Oral delay announcing equipment has recently been introduced at several of the larger trunk exchanges. This equipment is designed to give any one of ten announcements to a demand operator, e.g. ½ h delay, 1 h delay, 2 h delay, etc., etc. The general arrangement of the delay announcement machine is illustrated in Figs. 567 and 568. The ten announcements are recorded on a 12 in. glass disc as ten separate sound tracks of the "variable area" type (Fig. 569). The disc is rotated via reduction gears from a mains driven motor. A single projection lamp in conjunction with a system of condenser lenses focuses the light through the glass disc to a projection lens. A cylindrical lens is introduced between the condenser and the disc to produce a very narrow line of light at the disc which embraces the whole of the ten sound tracks. The projected image of the sound tracks passes through a narrow slit and then via ten separate lenses to ten photo-electric cells, each of which is wired to an amplifier. The amplifier is of the two-stage pentode type and the output is fed via a transformer to a specially designed master control panel (Fig. 570).

The master control panel consists of a number of rotary switches of the type commonly employed for wave change purposes in radio receivers. Each switch is labelled with the designation of the route and has ten positions to correspond to the ten verbal announcements from the machine. The contact arms of the announcement selection switches are wired to the tip and ring conductors of the jack associated with the route delay lamp. The third arc of the rotary switch applies battery to the delay lamp relay whenever the control switch is moved off normal.

When it is desired to take a particular route from demand into delay working, the supervisor ascertains the probable delay from the number of waiting calls and sets the control switch to the appropriate contact. This connects to the delay lamp jack the correct verbal announcement so that any operator throughout the exchange can ascertain the delay by inserting *any* plug in the delay jack of the route in question.

EXERCISES XIX

1. Explain the terms "Joint trunk working," "Demand working," "Toll working," and "Delay working " when applied to the methods of operating trunk and junction circuits.

2. Describe the process of setting up a call from a minor exchange, through a group centre and a zone centre to a dependent exchange in another zone. What procedure is adopted if the controlling operator finds the junctions at some distant point repeatedly engaged after several efforts have been made.

3. When is a long distance trunk route put into "delay working"? Describe the operating procedure on delayed trunk calls. How is the trunk demand operator advised of the probable delay on routes where delay working is in force?

4. Describe the system of pneumatic tubes provided at a large trunk exchange for the transmission of call tickets.

5. On a modern automanual switchboard multiple, the first free line in a group of outgoing junctions available to an operator is indicated by a single lamp glowing behind the designation strip. Describe, with the aid of a circuit diagram, how this facility is provided, and explain how the designation strip is made translucent. (*C. & G. Telephony, Grade III*, 1945.)

6. Explain, with reference to a simple circuit diagram, how the call-timing mechanism associated with a sleeve control cord circuit at a trunk exchange is started and stopped. (*C. & G. Telephony, II*, 1944.)

7. A subscriber on the main exchange in a non-director area dials 94, and is switched over to a direct junction to a distant trunk demand exchange at which sleeve control equipment is in use.

Give a diagram and a circuit description of the relay set on which the call is received at the trunk exchange. (*C. & G. Telephony, Grade II*, 1940.)

8. Describe the constructional features of a modern trunk switchboard. Give a typical key-shelf lay-out for a joint trunk position.

9. In some areas ordinary subscribers dial 94 for trunks and 0 for toll calls, whereas coin-box subscribers must dial "0" for all junction and trunk calls. Explain two methods of dealing with trunk calls from coin-box subscribers in such an area.

10. Describe the arrangements in the London area for dealing with trunk and toll calls.

11. How does the equipment at a sleeve control automanual exchange, which is also a group centre, differ from that at a minor exchange of the same type?

CHAPTER XX

POWER PLANT

ELECTRICAL energy is required in every telephone system for signalling, switching, the energization of subscribers' transmitters, and for many miscellaneous purposes. The consumption of such energy depends not only on the size of the exchange, but more particularly upon the signalling, switching, and transmission methods employed. In a magneto exchange, for example, the exchange power plant is called upon merely to supply current for the operators' transmitters, for local alarm circuits and for junction signalling; individual primary batteries being installed at the subscribers' premises for the energization of the transmitters. On the other hand, the power plant of an automatic exchange supplies energy for all the subscribers' transmitters, for signalling and for the control and operation of the automatic switching mechanisms. A modern exchange is, in fact, totally dependent upon the continuity of the supply of electrical energy at the exchange. The greatest possible care is therefore taken to ensure uninterrupted service by the provision of reserve energy to cover contingencies and by the duplication of the more important components of the power plant.

In very small public exchanges of the magneto and C.B.S. types, primary batteries can supply the comparatively small demands and, at the same time, provide a satisfactory reserve of energy. In the larger exchanges, and in fact at all exchanges employing central battery transmission, the energy consumption is too great for the use of primary cells. Although public electricity supply systems have now become very reliable, it is not good policy to make the communication system dependent upon the continuity of the electricity supply. Whilst it is generally more economical to utilize the public electricity mains as the *primary* source of energy for the exchange, storage batteries are almost invariably provided to give the necessary reserve in case of a mains failure. Broadly speaking, the exchange batteries are designed to give a 24-hour reserve of energy. In very large exchanges, and particularly where a common power plant serves two or more exchanges in the same building, alternative public supply mains are arranged wherever this is possible. In other circumstances, engine-driven generator sets are permanently installed for use in an emergency. In the smaller exchanges, provision is made for a prolonged failure of the public supply system by having available, at strategic centres, portable engine-driven generating sets.

The increased complexity of exchange design in recent years has made larger and larger demands on the power plant with a consequent increase in the capital cost of the latter. As a result, new methods have been introduced to supply power in the most economical way whilst, at the same time, providing the required security against breakdown. The modern tendency is to provide a power plant which is, as far as practicable, automatic in action and which requires a minimum of maintenance attention. Such semi-automatic and automatic power plants have been used particularly at automatic exchanges and are more fully described in Volume II.

Primary cells are now very little used for public exchange work except perhaps in small local battery areas where there are no public supply mains at the exchange. The general supersession of the magneto and C.B.S. systems has also largely eliminated the necessity for local batteries at the subscribers' premises. Primary batteries are nevertheless often the only practical means of supplying power for small P.M.B.X's and for plan number installations where intercommunication facilities are required.

Leclanché Cells. The Leclanché cell has for many years been the only type of primary cell used in telephony. The capital cost is low and the components of the cell are readily obtainable. Moreover, it has a relatively high e.m.f. for a primary cell and a fairly low internal resistance. The amount of local action is small, and the cell can be left for prolonged periods without maintenance attention. The Leclanché cell is particularly suitable for conditions where the current is small and intermittent.

The Leclanché cell employs electrodes of carbon and zinc immersed in a solution of a chloride salt. The depolarizing agent is solid manganese dioxide (MnO_2) which is arranged round the carbon rod. In most commercial Leclanché cells the electrolyte consists of a 15 per cent (by weight) solution of ammonium chloride (sal-ammoniac) (NH_4Cl). When the external circuit between the carbon and zinc electrodes is completed, current flows through the cell from zinc to carbon and the electrolyte is decomposed into a positive ion ($+ NH_4$) and a negative ion ($- Cl$). The negative chlorine ion

travels to the higher potential zinc electrode where it combines with the zinc to form zinc chloride ($ZnCl_2$). The positive (NH_4) ion is discharged at the carbon plate and decomposes into hydrogen (H) and ammonia (NH_3). The latter readily dissolves in the solution whilst the hydrogen combines with the manganese dioxide (MnO_2) to give brown oxide of manganese (Mn_2O_3). Thus, the chemical actions in a Leclanché cell during discharge may be summarized as follows:

$$2NH_4Cl + Zn \rightarrow ZnCl_2 + 2NH_3 + 2H.$$

The subsequent depolarization is given by:

$$2H + 2MnO_2 \rightarrow H_2O + Mn_2O_3.$$

In practice the reactions are somewhat more involved than the above and complex compounds are formed on the surface of the zinc and depolarizer as the cell becomes exhausted. Although the ammonia gas liberated in a Leclanché cell during discharge is largely dissolved in the electrolyte, a certain amount of free ammonia gas escapes into the atmosphere. This gas has a deleterious effect upon metalwork and adequate ventilation is therefore desirable. On the other hand, the provision of ventilation increases the rate of evaporation of the electrolyte and the amount of maintenance attention necessary. In order to minimize the maintenance costs, it is the practice in the Post Office to use manganese chloride ($MnCl_2$) instead of ammonium chloride for the electrolyte of Leclanché cells where the discharge rate is low. The chemical action when manganese chloride is used is:

$$Zn + MnCl_2 \rightarrow ZnCl_2 + Mn.$$

The depolarizing reactions are:

$$Mn + 3MnO_2 \rightarrow 2Mn_2O_3.$$

It will be seen that when manganese chloride is used no gas is generated and the cells can be sealed in an airtight box to prevent evaporation of the electrolyte. If the cells are not so sealed an oxide tends to form on the zinc rod which raises the internal resistance of the cell. Ammonium chloride is somewhat better than manganese chloride where the discharge rate is high and is used by the Post Office in the larger types of cell.

Wet Cells. Fig. 571 shows a typical Leclanché cell of the wet type. The outer container is either of glass or glazed stoneware, whilst the zinc is usually in the form of a rod which is suspended from the lip of the container. In some cases the zinc rod is tapered as in Fig. 572, so that the maximum diameter is available at the point where the chemical action is greatest. The zinc is invariably amalgamated with mercury and strong acid to minimize local action (i.e. chemical action set up by dissimilar metals on the surface of the zinc).

Where ammonium chloride is used for the electrolyte, it has been found that the addition of a small quantity of zinc chloride reduces the amount of polarization and tends to minimize the formation of salts on the cell elements. Special lozenges consisting of a mixture of 85 per cent ammonium chloride and 15 per cent zinc chloride are available and provide a ready means of preparing the electrolyte. The depolarizing agent of

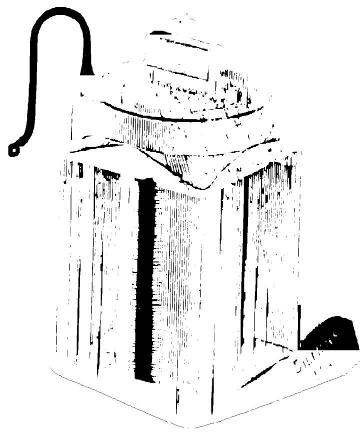


FIG. 571. POROUS POT TYPE OF LECLANCHÉ CELL



FIG. 572. TAPERED ZINC ROD FOR LECLANCHÉ CELL

the Leclanché cell (manganese dioxide) has a high resistance and hence, in order to minimize the internal resistance of the cell, it is usual to mix the depolarizing agent with a quantity of graphite or carbon. In the type of cell illustrated in Fig. 571 the carbon rod is placed centrally in a porous pot and the intervening space is tightly packed with a mixture of manganese dioxide and carbon. The porous pot method of construction has now been largely superseded by the *sack* type in which the depolarizing material is wrapped and bound up tightly in calico or some similar fabric. This method of construction provides a cell of lower

internal resistance than one with a porous pot and is also cheaper. Fig. 573 shows a large type sack element.

In recent years there has been a considerable degree of standardization of Leclanché cells. The various standard types are detailed in British Standard Specification No. 397, and the following tabulation shows the main types used by the Post Office:

Code	Overall Size		Capacity	
	height (in.)	diam. (in.)	watt-hours	discharge rate (mA)
WK1	8½	6½	200	100
WK2	8½	5	75	50
WK4	7½	3½	40	20

The capacity of a primary cell varies greatly with the rate of discharge and with the conditions of use (i.e. intermittent or continuous working). The watt-hours output also depends upon the minimum voltage to which the cell can be allowed to discharge. The capacity figures given in the above table are minimum figures with the specified rate of discharge and are based on the assumption that the discharge is intermittent and at the rate of 5 hours per day for 6 days per week, and assume that the cell is allowed to discharge until its p.d. falls to 0·9 V.

Dry Cells. In the so-called *dry* type of Leclanché cell the electrolyte is in the form of a paste which is held by an absorbent material in such a way that it will not flow out of the container even if the cell is inverted. Figs. 574 and 575 show a typical dry cell of medium size. The construction is self-explanatory from the illustrations. As with the wet type of cell, the sizes of dry cells are standardized. The more common types used in the Post Office are as follows:

Code	Height (in.)	Diam. or side (in.)	Capacity	
			watt-hours	discharge rate (mA)
DR2	7	2½	45	50
DS1	8	4½	135	150
DS5	5½	2	22	20
DS6	4½	1½	10	10

Dry cells are more expensive than cells of the wet type and their use is restricted to circumstances where it would be impracticable or inadvisable to

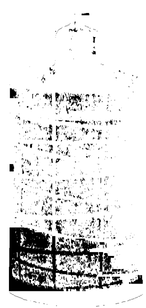


Fig. 573
"Sack" Type
Leclanché
Element
(Type WK1)



Fig. 574
Dry Cell
(Type DR2)

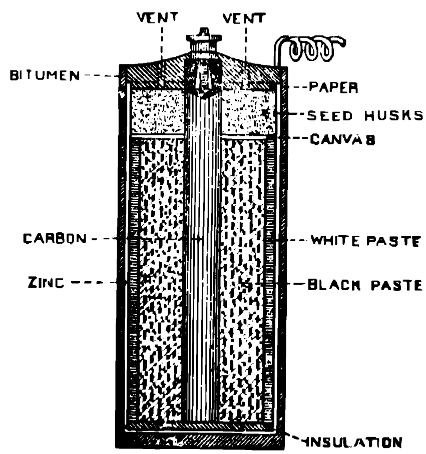


Fig. 575. Section of Typical Dry Cell

use the wet type of cell (e.g. in portable equipment, in luxuriously furnished rooms, etc.).

Testing of Primary Cells. A Leclanché cell when new has an e.m.f. of approximately 1·5 V. During the life of the cell the e.m.f. gradually decreases until the cell is incapable of giving much further service. At the same time the internal resistance (which is usually something less than 0·5 Ω when new) gradually increases during the life of the cell. When the cell is on load, the voltage drop is proportional to the internal resistance and

the current. Hence, the effective p.d. at the terminals of the cell is (for a given current) determined partly by the e.m.f. of the cell and partly by its internal resistance. The failure of a cell in service may therefore be due to a fall in the e.m.f. of the cell or to an increase in the internal resistance, or to both. With dry cells the cause of failure is not material since the whole cell must in any case be replaced, but with the wet type of cell it is important to determine the cause of failure in order to decide whether the depolarizing element, the electrolyte or the zinc electrode requires renewal. The following testing procedure is adopted:

(*a*) The open circuit voltage of the cell is read by means of a high resistance voltmeter. Assume that this voltage is V_1.

(*b*) A resistance of 2 Ω is connected across the cell and the terminal p.d. is read *immediately*. Assume that this voltage is V_2.

(*c*) The resistance is applied for one minute and then removed. The open circuit voltage is now read again immediately after the disconnexion of the resistance. Assume that this voltage is V_3.

It is clear that:

(*a*) The difference between V_1 and V_3 is a measure of the efficiency of the depolarizer. A big difference between these two voltages indicates a high degree of polarization and the need for renewal of the depolarizing element.

(*b*) The internal resistance of the cell is, from Ohm's Law, given by:

$$r = \frac{2(V_1 - V_2)}{V_2} \text{ (ohms).}$$

A low value for V_2 indicates a high internal resistance which may be due to an exhausted electrolyte or to a high resistance at the surface of the sack or zinc electrode.

In practice the depolarizing element is considered to be unsatisfactory if V_3 is less than 1·2 V. If V_2 is less than 0·5 V for small cells or 0·8 V for the larger cells, it is considered unsatisfactory and indicates that the electrolyte, the zinc and the surface of the sack require attention.

It is preferable that the test should be carried out on the battery as a whole rather than on individual cells. In these circumstances the resistance to be used should have a value of 2 multiplied by the number of cells, and the voltage readings indicated above should also be multiplied by the number of cells. By treating the battery as a unit, the whole battery can be put in good condition, thereby avoiding frequent maintenance visits to the installation. Tests on primary batteries are facilitated by the use of specially designed resistor coil. The unit contains 6 resistance coils which are brought out to terminals as shown in Fig. 576. By the use of this

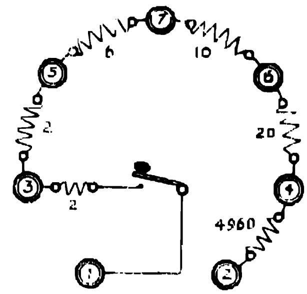


FIG. 576. RESISTANCE COIL FOR TESTING BATTERIES
(Coil Testing No. 1)

testing coil it is possible to obtain the correct value of resistance for application to batteries of various sizes.

Secondary Cells. A *secondary cell* or *accumulator* may be regarded as a reversible cell in which chemical energy can be converted into electrical energy during discharge of the cell, whilst electrical energy can be converted to chemical energy during the charging process. The lead-acid type of secondary cell is by far the most common type in use to-day. The cell is made up of positive and negative lead plates with an electrolyte of dilute sulphuric acid. When the cell is in a discharged state, the active material on both plates consists mainly of lead sulphate ($PbSO_4$). The electrolysis due to the passage of the charging current produces positively charged hydrogen ions (+ H) which travel to the negative plates of the cell and there combine with the lead sulphate ($PbSO_4$) to form spongy lead (Pb) and sulphuric acid (H_2SO_4). At the same time, the negatively charged sulphions ($- SO_4$) move to the positive plates and there combine with the lead sulphate and the water of the electrolyte to form lead peroxide (PbO_2) and sulphuric acid (H_2SO_4). The reactions during charge may be summarized as follows:

Positive plate: $PbSO_4 + SO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4$.

Negative plate: $PbSO_4 + 2H \rightarrow Pb + H_2SO_4$.

The reverse process takes place during discharge of the cell. The hydrogen ions now travel to the positive plates where they combine with the lead peroxide (PbO_2) and the sulphuric acid (H_2SO_4) to form lead sulphate ($PbSO_4$) and water (H_2O). The negatively charged SO_4 ions, after giving up their charge, combine with the lead at the negative

plates to form lead sulphate ($PbSO_4$). Thus, the reactions during discharge are:

Positive plate: $PbO_2 + 2H + H_2SO_4 \rightarrow PbSO_4 + 2H_2O$.

Negative plate: $Pb + SO_4 \rightarrow PbSO_4$.

In practice the chemical reactions are somewhat more involved than as described above and do not extend to the full limits of the available material on the plates, i.e. the discharge is stopped before all the active material on the plates is converted to lead sulphate, and the electrolyte to water.

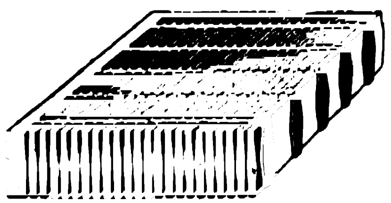


FIG. 577. PLANTÉ PLATE WITHOUT CORE

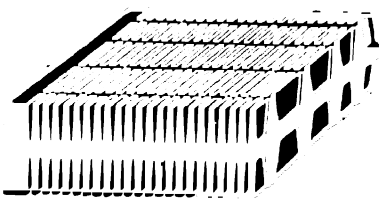


FIG. 578. PLANTÉ PLATE WITH CORE

Conversely, the charge is stopped before the positive plate is wholly converted to lead peroxide and the negative plate to lead.

Plates. Pure lead (containing not more than 0·005 per cent of foreign matter) is necessary for the construction of secondary cell plates. This material is very soft and has little tensile strength and in some cases it is necessary to add antimony to obtain the required mechanical characteristics. The active material may be supplied either by forming it out of, and on, the plate itself or by applying it in the form of a paste. Modern practice favours *Planté or formed positives* with *Faure or pasted negatives*—the formed negative having disappeared entirely. Improvements in Planté plates have for their object—

(1) The simplification of the process of formation either by chemical process, the passage of current, or a combination of both;

(2) Improvement of the mechanical design so as to equalize the stresses on charge and discharge over the whole surface of the plate, and, hence, to ensure a long life; and

(3) The increasing of the volume of active material.

In pasted plates, the problem is chiefly in the direction of securing better adherence between the plates and the paste.

Secondary cells are made by many manufacturers, and differ somewhat in constructional detail, but more especially in the paste employed. The present account is therefore confined to general principles.

Planté Positives. The Planté positive plate consists of a lead sheet with a large number of deep vertical grooves to increase its superficial area. (An increase in area of from 7 to 10 times can be obtained.) Fig. 577 shows a section of a common type of plate where the grooves extend right through the plate. In other designs (Fig. 578) there is a thin central wall or *core* to give additional mechanical strength.

The forming process, in which the active material is produced, varies with different manufacturers. In one method, the forming is completed in three separate stages:

(1) In the first stage, the plates are immersed in dilute sulphuric acid to which is added a *forming or corrosive agent* such as hydrochloric or nitric acid. The forming agent produces a thin film of soluble lead salt which is converted to lead sulphate by the action of the sulphuric acid. A current is now passed from the plate to the electrolyte in order to oxidize the lead sulphate and convert it to lead peroxide. This process is continued until the required thickness (approx. 0·02 in.) of lead peroxide is produced. The quantity of the forming agent is adjusted so that substantially none remains at the completion of this stage.

(2) The second stage consists of reversing the current so that the skin of lead peroxide is converted to spongy lead. During this stage, all traces of the forming agent are removed from the plate.

(3) The electrolyte is replaced by clean dilute sulphuric acid for the third stage in the forming process. The current is again reversed and in due course the spongy lead is reconverted to lead peroxide. This completes the forming process.

Fig. 579 shows a typical positive plate of the Planté type. Fig. 580 shows an alternative form of construction and is commonly known as a *rosette* type of plate. The plate itself is perforated

with a large number of round holes into which are pressed rolls (or rosettes) of corrugated lead strip. The active material is formed on the surface of this lead strip.

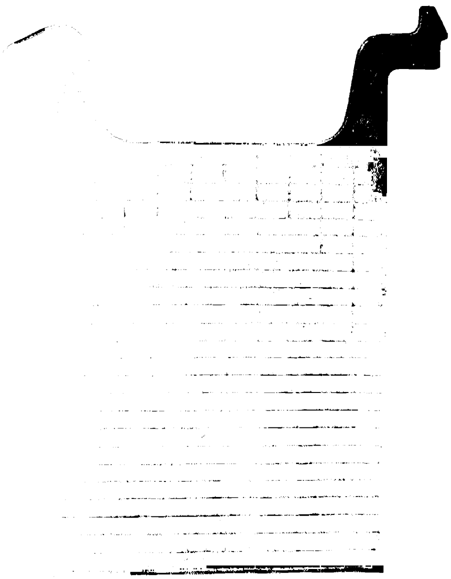


Fig. 579 Typical Planté Positive Plate

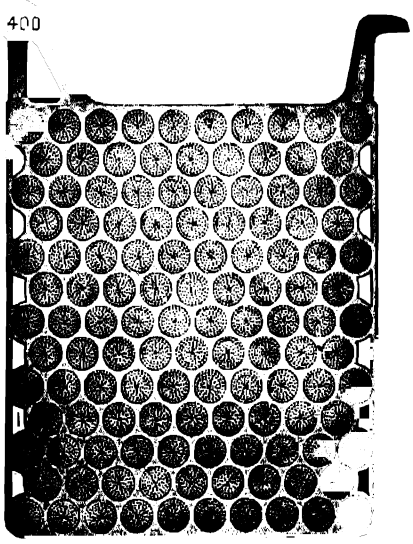


Fig. 580. Rosette Type Positive Plate

Planté positive plates have proved highly successful over many years of use, and are found to maintain their capacity throughout their useful life. Although some active material is lost from the surface of the plate due to gassing, it is replaced by the formation of new lead peroxide from the underlying lead. As this process continues during the life of the plate, there is some physical expansion (up to about 5 per cent) owing to the greater volume of the lead peroxide. It is found, however, that with the construction shown in Figs. 577 and 578, most of the expansion occurs in a downward direction and does not lead to buckling of the plate.

Faure Plates. Plates produced by the Faure process consist of a grid or box of lead-antimony alloy



Fig. 581. Box Type Negative Plate

and the active material is in the form of a paste which is pressed into compartments of the plate. Both positive and negative plates can be of the Faure type but, in most larger batteries, the positive plates are of the Planté type with Faure type negatives. Semi-Planté positive plates, which combine the Planté and Faure methods, are sometimes used in small batteries. Such plates are provided with horizontal grooves which are initially filled with paste but, as the paste is lost during the working of the cell, a film of active material is formed on the surfaces of the grooves. The semi-Planté plate is generally less satisfactory than the full Planté type when the cell is subject to heavy discharge rates. There is also a greater tendency to lateral growth and buckling with this form of plate. In the true Faure plate, the paste can either be pressed into cavities in the surface of the plate or, alternatively, enclosed in a box

of perforated sheet lead. Plates constructed on the latter principle are generally known as *Box type plates* (Fig. 581).

The paste for Faure plates is manufactured chiefly from lead oxides such as litharge (PbO) or minium (Pb_3O_4) to which is added small quantities of other substances known as "reducing," "porosity," "cementing," "hardening," and "expanding" agents. The reducing agent (e.g. ammonium sulphate) accelerates the formation of the active material whilst the porosity agent (e.g. magnesium sulphate) makes the paste porous to facilitate subsequent chemical action. The hardening agent (e.g. glycerine) binds the other ingredients together

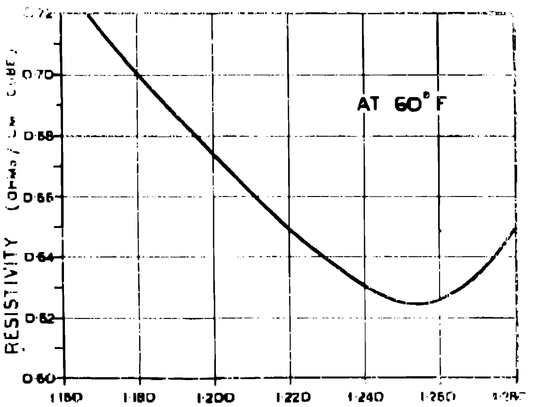


Fig. 582. Effect of Specific Gravity on Resistance of Electrolyte

and increases the conductivity of the paste. The expanding agent is usually an inert substance (e.g. ground pumice or porcelain) which prevents consolidation of the paste under working conditions.

After pasting, the plates are immersed in an electrolyte of dilute sulphuric acid and a current is passed from the positive to the negative plates. The action of the sulphuric acid converts the lead oxides of the paste to lead sulphate and the electrolytic action gradually changes the lead sulphate to lead peroxide at the positive plates and to spongy lead at the negative plates.

Electrolyte. It has been stated that the electrolyte of a secondary cell is a solution of sulphuric acid (H_2SO_4) in water (H_2O). Pure sulphuric acid has a specific gravity of approximately 1·84 and is normally diluted with distilled water until the specific gravity when the cell is charged is approximately 1·215. The exact value of the specific gravity is not critical, but the most satisfactory operation is obtainable when the specific gravity is roughly between 1·100 and 1·300. Between these limits the resistance of the electrolyte (and hence the internal resistance of the cell) is a minimum (Fig. 582). If the specific gravity is allowed to fall below about 1·100, damage may be caused by the plates becoming hydrated. If, on the other hand, the specific gravity is above 1·300, corrosion of the plates may take place. The density of the electrolyte also determines the e.m.f. of a fully charged cell. The relationship is shown in Fig. 583 from which it will be noted that within normal limits, the e.m.f. rises approximately in direct proportion to the specific gravity of the electrolyte.

The electrolyte used in a cell must be pure. The presence of metallic impurities causes local

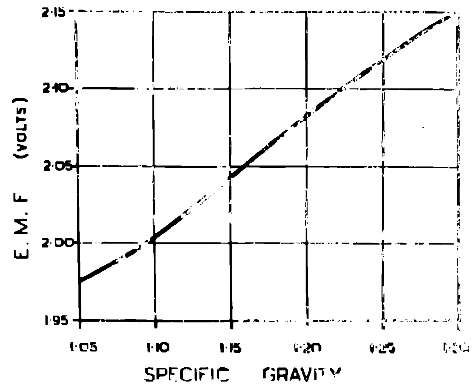


Fig. 583. Effect of Specific Gravity on the E.M.F. of a Fully Charged Cell

action and the consequent internal discharge of the cell. Iron is possibly the most common metallic impurity and can often be detected by the usual "rusty" colour of the positive plates. Non-metallic substances, such as chlorine, ammonia, arsenic, etc., react with the metallic lead of the plates and ultimately cause their destruction. The P.O. specification lays down that the quantity of impurities per 100 cu. cm. of electrolyte shall not exceed the following values:

Residual of evaporation	0·05	gramme
Iron	0·002	,,
Manganese	0·00035	,,
Copper	0·001	,,
Arsenic	0·001	,,
Ammonia	0·01	,,
Nitrogen	0·001	,,
Chlorine	0·001	,,
Sulphurous Acid	0·001	,,

The electrolyte is normally tested at 60° F. and 1·205 specific gravity, and it must be colourless when viewed through 12 in. of the medium.

Some years ago distilled water was invariably used for "topping up" the electrolyte to make up the losses caused by evaporation. It was found from experience, however, that in most circumstances

tap water is satisfactory for topping up. Investigations have shown that of all the various impurities in tap water, only iron and chlorine occur in sufficient quantities to be detrimental to the cells. The use of tap water is now authorized in all cases where the cell capacity does not exceed 300 Ah. For larger cells tap water can be used if analysis shows that the iron and chlorine contents are within the following figures:

Iron	1 part in 200 000
Chlorine	1 part in 50 000

In the past, evaporation and loss of electrolyte due to spray have been minimized by a thin film

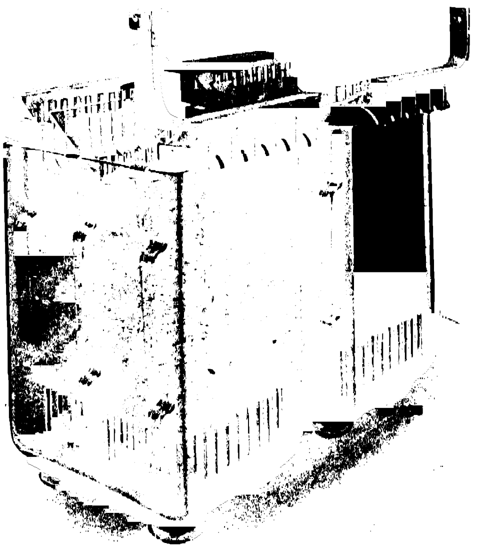


FIG. 584. 300 AH CELLS OF THE GLASS BOX TYPE

of highly refined petroleum oil on the surface of the electrolyte. Experience has shown that the use of oil has, in some instances, a deleterious effect on the cell. The use of oil is now limited to those cases where open type cells are located in the same room as other apparatus and where corrosion from the acid fumes is likely to occur.

Types of Cell. Apart from cells of special design for portable apparatus, etc., there are three main types of secondary cell:

(*a*) *Enclosed cells* where the container is closed by a moulded composition lid through which the terminal posts project. Vent plugs are provided to permit the free escape of gases, but the design is such that the loss of electrolyte due to evaporation or spray is small. This type is used where the cells must be located in the same room as telephone apparatus and in other circumstances where cells of small capacity are required. There are five standard sizes of enclosed secondary cells (Nos. 1–5) with a capacity range of from 10 to 125 Ah.

(*b*) *Glass box cells* for general use where a capacity of not more than 300 Ah is required. Fig. 584 shows typical cells of the glass box type. The plates are suspended from the top of the box by means of projecting lugs cast on the plates themselves. Glass rod separators are employed and are located by grooves cast in the negative plates, whilst the assembly of plates and separators is held together by springy lead strips inserted between the end plates and the glass box. Sheet glass arrestors are placed on top of the separator rods to minimize the loss of electrolyte due to spray. The following schedule shows the various standard types of glass box cell. It will be noted that there are only two standard plate sizes, the various capacities being obtained by adjusting the number of plates.

Code	Plate Size	No. of Positives	No. of Negatives	Capacity (Ah)
No. 6	5 in. × 6½ in.	3	4	72
No. 7	5 in. × 6½ in.	4	5	96
No. 8	5 in × 6½ in.	5	6	120
No. 9	7 in. × 9¾ in.	4	5	200
No. 10	7 in. × 9¾ in.	5	6	250
No. 11	7 in. × 9¾ in.	6	7	300

(*c*) *Lead-lined wood-box cells* for use where the capacity required cannot be obtained with cells of the glass box type. The outer container is constructed of good quality timber, well jointed at the corners, and the interior is protected from the action of sulphuric acid by impregnating with wax. No metals which would be attacked by sulphuric acid are used in the construction of the box and the whole of the exterior surface is treated with acid resisting paint. The box is lined with lead sheet which is rigorously tested for pin holes, local action, and other defects. The plates are usually supported by glass slabs which are kept in position by means of lead lugs burned on to the lead lining at the bottom and sides of the box. Glass rod separators (which can readily be removed for maintenance) provide the necessary spacing between the plates.

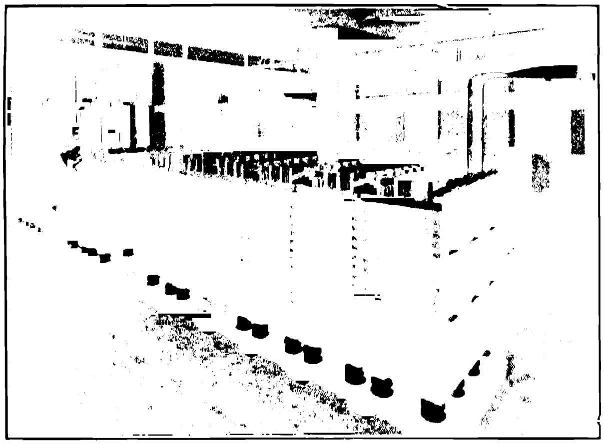


FIG. 585. A 22 V BATTERY OF 5650 AH CAPACITY

It is sometimes desirable, on economic grounds, to install battery boxes which, although too large for the initial needs, will ultimately be necesary to meet the requirements of the exchange. In such cases, the boxes are only partially plated at the outset and an acid-tight lead partition is fitted in the box so as to reduce the amount of electrolyte which will take part in the reactions of the cell. It is usual to fill the unplated portion of the box with acid in order to equalize the pressure on both sides of the lead partition. Fig. 585 gives a general view of a battery room with lead-lined wood-box secondary cells.

Change of Specific Gravity. It has been seen from the chemical reactions of a secondary cell that, during discharge, sulphuric acid of the electrotype is converted to water, whilst during the charging process some of the water content of the electrolyte is converted into sulphuric acid. The specific gravity of the electrolyte is therefore a good indication of the state of discharge of a secondary cell. Fig. 586 shows typical curves of the variation on specific gravity during charge and discharge. Apart from a slight curvature at the commencement of the discharge (due to diffusion), the specific gravity decreases uniformly during the discharge period. In a similar way, the specific gravity of the electrolyte increases uniformly during the charging period until the cell is almost fully charged, when "gassing" somewhat flattens out the curve. The rise of specific gravity after the end of the charge, and the fall after the end of discharge, is due to the diffusion of the electrolyte which makes the change of specific gravity lag somewhat behind the charge or discharge current.

It is clear from Fig. 586 that, if the range of specific gravity and the capacity of the battery are known, it is possible to determine the residual capacity at any time by the measurement of the specific gravity of the electrolyte. For example, if the specific gravity of a fully charged cell is 1·215, the specific gravity of the cell when it is completely discharged is 1·175, and the capacity of the battery is, say, 400 Ah, then the specific gravity will drop by approximately 0·001 for every 10 Ah of discharge. Thus, if at a given time the specific gravity of the cell is 1·195 it can be stated with reasonable accuracy that there are 200 Ah left in the cell.

The Hydrometer. The specific gravity of a cell is measured by means of a hydrometer. A common type of hydrometer (Fig. 587) consists of a flat glass bulb loaded at the bottom with lead shot and having a vertical scale. The hydrometer is calibrated to read from 1·170 to 1·220 with divisions at intervals of 0·001. It is so designed that, when floated in a cell, the hydrometer sinks to such a position that the surface of the electrolyte indicates the specific gravity.

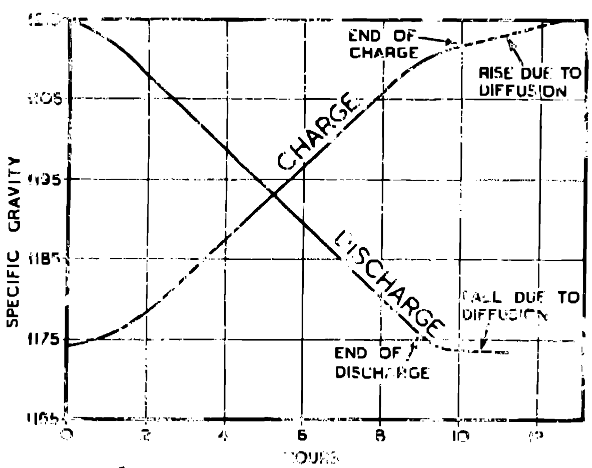


FIG. 586. CHANGE OF SPECIFIC GRAVITY DURING CHARGE AND DISCHARGE

There is sometimes difficulty in obtaining accurate readings with an ordinary hydrometer due to the relative position of the plates, container and the level of the electrolyte. In such circumstances the hydrometer illustrated in Fig. 588 is preferable. With this design, the "reading line" is raised above the level of the electrolyte by the use of a float. The hydrometer proper is, of course, specially calibrated for use in conjunction with the float. The float type of hydrometer also eliminates the

errors of reading due to the surface tension which causes the electrolyte to "heap up" round the stem of an ordinary hydrometer.

If the capacity of a battery is known and its specific gravity range is obtained either by calculation or from a test discharge, it is possible to



FIG. 587
HYDROMETER

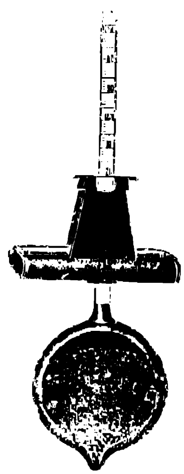


FIG. 588
HYDROMETER
WITH FLOAT
(Luesmart type)

determine the ampere-hours per hydrometer division. From this information the residual capacity in a battery can readily be determined by taking hydrometer readings. In this connexion, the specific gravity of the electrolyte is to some extent dependent upon the temperature. An increase of temperature above a normal figure of 60° F. causes the specific gravity to decrease whilst a decrease of temperature below 60° F. increases the specific gravity. The variation is approximately 0·0003 or one-third of a hydrometer division per degree Fahrenheit. Allowance must be made for this in determining the residual capacity of a battery from the hydrometer readings.

Voltage during Charge. Fig. 589 shows how the terminal voltage of a cell rises during charge. The rapid rise of p.d. at the commencement of the charge is mainly due to the polarization back e.m.f. The steady rise which follows is due partly to the increase in density of the electrolyte, and partly to the increase in potential of the positive plates. At a late stage in the charging period, the quantity of lead sulphate remaining on the plates is small and most of the energy is being used in the decomposition of the water of the electrolyte. The voltage of the cell at this stage depends largely

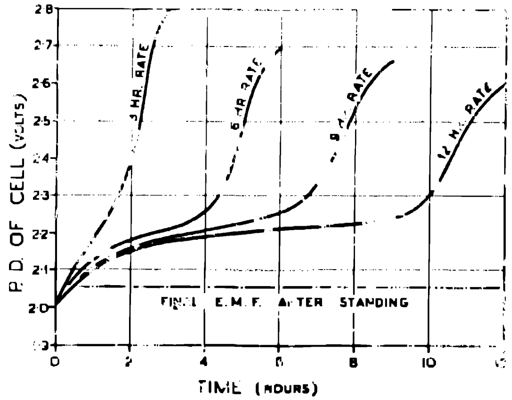


FIG. 589. TERMINAL P.D. OF A CELL DURING CHARGE

on the rate of decomposition, i.e. on the charging current. The voltage attained at the end of the charge is, therefore, governed to a large extent by the charging rate.

The curves of Fig. 589 show the actual potential difference at the terminals of the cell, whilst charging is in progress. When the charging current is disconnected, the e.m.f. rapidly falls to approximately 2·15 V and there is a further gradual fall during the next twenty-four hours until the e.m.f. finally settles at about 2·05 V.

Voltage during Discharge. The fall of terminal p.d. as a cell is discharged is shown in Fig. 590. The fall is due partly to the decrease in the potential of the plates as the active material is converted to lead sulphate and partly to an increase in the potential drop in the cell as the electrolyte becomes less dense and of higher resistivity. At high rates of discharge, the electrolyte of low density in contact with the plates does not have time to diffuse and the internal resistance of the cell tends to increase. The high internal resistance coupled with the high value of current produces a greater internal potential drop and a lower terminal p.d. than at lower discharge rates.

Capacity of a Cell. The ampere-hour capacity of a secondary cell depends upon:

(*a*) The quantity and condition of the active material.

(*b*) The design of the plates.

(*c*) The density and quantity of the electrolyte.

(*d*) The ease which the electrolyte can circulate or diffuse round the plates.

(*e*) The rate of discharge.

(*f*) The temperature.

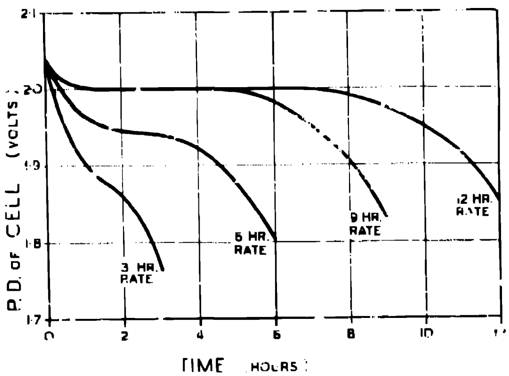


Fig. 590. Terminal P.D. of a Cell during Discharge

The quantity of active material depends upon the size and number of plates and upon the extent of the forming process. The general condition and porosity of the active material is determined in the first place by the care taken during manufacture and later by the treatment of the cell in service. There is a critical density of electrolyte which will give the maximum capacity at any given rate of discharge. High rates of discharge require a higher specific gravity than low rates, but in practice it is usual to standardize the specific gravity at a value suitable for average conditions.

It has been seen that, during discharge, the specific gravity of the electrolyte in the vicinity (and pores) of the plates rapidly decreases—the rate of decrease being dependent upon the discharge rate. The low density electrolyte in contact with the plates offers a high resistance to the current and is responsible for a considerable proportion of the potential drop in the cell. If the design of the cell and the discharge current are such that the weak electrolyte at the surface of the plates cannot be replaced by diffusion, the potential drop rises rapidly and the terminal p.d. of the cell collapses. With a cell of given design, the point at which this rapid fall of p.d. occurs is dependent upon the value of the discharge current. It follows that the ampere-hours which can be taken out of a cell before the voltage collapses is affected by the rate of discharge. Fig. 591 shows how the capacity of a cell varies with the discharge time. It is usual to express the capacity of a cell in terms of the ampere-hours which can be taken from the cell when it is discharged over a period of 9 hours. (This is known

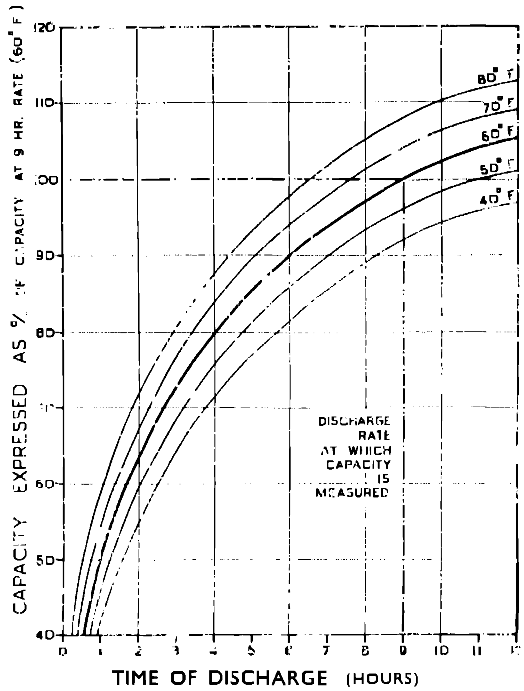


Fig. 591. Capacity of a Cell at Various Discharge Rates and Temperatures

as the 9-hour discharge rate.) In Fig. 591 the capacity at other rates of discharge is shown as a percentage of the capacity at the 9-hour rate. It will be noted that the capacity of a cell when it is discharged in a period of 3 hours is only about 70 per cent of the rated capacity (at the 9-hour rate).

The temperature has also a material effect on the capacity of a cell. An increase in temperature causes a slight increase in the potential of the plates, a decrease in the resistance of the electrolyte and an increased rate of diffusion due to the electrolyte becoming less viscous. These effects combine to give an increased capacity at high temperatures or, conversely, a lower capacity at low temperatures. The nominal capacity of a cell is measured at a temperature of 60° F. and

allowance can be made for temperature variations by adding or subtracting 0·5 per cent of the nominal capacity for each degree Fahrenheit above or below 60° F. The correction factor varies somewhat with the discharge rate and may vary from 0·2 to 1·0 per cent as the discharge rate is increased from the 25-hour rate to the 1-hour rate. Fig. 591 shows the effect of temperature as well as of discharge rate on the capacity of a cell.

Efficiency of Battery. The efficiency of a secondary cell battery can be expressed in terms of either the capacity (ampere-hours) or the energy (watt-hours). The *ampere-hour efficiency* is the ratio of the quantity of electricity which can be taken out of the battery to the quantity which must be put back to restore it to its original condition, i.e.

if i = average discharge current (amps),
t = time of discharge (hours),
I = average charging current (amps),
and T = time of charge (hours),
then:

$$\text{Ampere-hour Efficiency} = \frac{i \times t}{I \times T} \times 100\%.$$

The ampere-hour efficiency obtainable under normal working conditions is in the order of 90 to 95 per cent.

For some purposes it is more important to know the *watt-hour efficiency* of a battery. The number of watt-hours put into or taken out of a battery is determined by the average voltage, the average current and the time, i.e.

$$\text{Watt-hour Efficiency} = \frac{i \times v \times t}{I \times V \times T} \times 100\%,$$

where v = average p.d. during discharge (volts)
and V = average p.d. during charge (volts).

It is clear that the watt-hour efficiency can be obtained by multiplying the ampere-hour efficiency by the ratio of the average voltage on discharge to the average voltage during charge. As is to be expected the watt-hour efficiency is somewhat lower than the ampere-hour efficiency and varies in practice from about 70 to 80 per cent. The watt-hour efficiency is, of course, dependent upon the rates of charge and discharge. At low rates, the voltage drop due to the passage of the current through the battery is small, and hence the watt-hour efficiency is high.

Initial Charge. When new secondary cells are installed, they are invariably given a prolonged initial charge to prepare the plates for the working conditions. After the cells have been assembled, the containers are filled with dilute sulphuric acid of 1·215 specific gravity. The battery is then put on charge as soon as possible at the 18-hour rate (i.e. at a current which is given by the nominal capacity divided by 18). The specific gravity of the electrolyte should be recorded at regular intervals. It will be found that the value will fall at first, reach a minimum after some hours, and then gradually rise. When the first rise in specific gravity is observed, the current should be increased to the 9-hour rate (i.e. doubled) and the charge should be continued at the increased rate until the battery is fully charged. The battery may be regarded as fully charged when:

(*a*) The specific gravity of each cell remains substantially steady for at least 2 hours.

(*b*) The terminal voltage of each cell remains steady at approximately 2·65 V.

(*c*) Each plate is gassing freely.

Approximately one hour after the completion of the initial charge, the specific gravity of the electrolyte should be adjusted (by the addition of strong sulphuric acid or distilled water) to a value of 1·215.

Some 12 to 18 hours after the completion of the initial charge, the battery is ready for a test discharge.

Test Discharge. For the test discharge an artificial load (generally a liquid resistance) is applied to the battery. The value of the current is adjusted so that the battery discharges at the 9-hour rate and the discharge is continued until the p.d. of the cells falls to 1·83 V. A record is taken, during the discharge, of the specific gravity readings, temperature, and the voltage of each cell. It is generally satisfactory to take readings at hourly intervals with somewhat more frequent observations at the beginning and towards the end of the discharge. The specific gravity readings are, of course, corrected for temperature variations and at the completion of the test discharge it should be possible to determine the specific gravity range of the battery, the total capacity of the battery and the ampere-hours per hydrometer division.

Charging Procedure. At installations where the batteries are worked on a charge-discharge basis (*q.v.*) there is a definite charging procedure which is designed to minimize power wastage, to reduce the amount of maintenance and to prolong the life of the battery. If, after discharge, a battery is fully charged so that all cells are gassing freely, the charging current towards the end of the charge is largely used in converting the water of the electrolyte into its constituent gases. This involves a considerable waste of electrical energy, and the vigorous gassing of the cells tends to loosen the

active material from the plates and thereby shorten their life. Moreover, extensive gassing quickly reduces the level of the electrolyte so that the cells require frequent topping up. It has been found that, provided a battery is fully charged, say, once in three months, it is possible to curtail the intermediate charges without any detrimental effect.

It is now the standard practice at telephone exchanges to give what is known as an *ordinary charge* as required, and to supplement this by an *equalizing charge* at regular intervals. At unattended exchanges, the equalizing charge is given every three months, but, where there is continuous attendance, equalizing charges are given at monthly intervals. During an ordinary charge, the current is adjusted to the rate which gives the maximum efficiency of the charging plant provided that the charging current does not exceed the 4½-hour rate. When the average voltage of the cells reaches 2·35 V, the charging current is cut down to the 12-hour rate. This very materially reduces the amount of gassing. The charge is finally terminated when the hydrometer readings (corrected for temperature) indicate an input of 93 per cent of the total capacity. If, for example, the specific gravity of a battery when it is fully charged is 1·215, and the specific gravity range for a complete discharge is 50 hydrometer divisions, an ordinary charge is terminated when the hydrometer indicates a rise of specific gravity of $93/100 \times 50 = 46{\cdot}5$ divisions. This occurs when the specific gravity reading is $50 - 46{\cdot}5 = 3{\cdot}5$ divisions below the full charge figure of 1·215, i.e. the charge is terminated when the hydrometer reads 1211·5 divisions. Normally, for a new battery, the ampere-hour input during an ordinary charge is about 11 or 12 per cent in excess of a full discharge, but this figure may rise to from 15 to 20 per cent when the battery has been in service for some years.

The equalizing charge is given in the manner already described for an ordinary charge, but is prolonged until the specific gravity of each cell is substantially constant. During the concluding stages of an equalizing charge, the hydrometer reading of each cell should be taken at ½-hourly intervals. The charge is finally terminated when the specific gravity has stabilized to within half a hydrometer division. The ampere-hour input during any equalizing charge may be between 15 and 20 per cent in excess of a full discharge, but this value may increase to about 25 per cent with an older battery.

Discharging Procedure. On economic grounds it is very undesirable that batteries should be re-charged before they are fully discharged. If a battery is prematurely taken off discharge, the power efficiency of the installation is reduced. This practice does, moreover, necessitate a greater number of charge-discharge cycles within a given period and thereby shortens the life of the battery. On the other hand, over-discharging may cause permanent damage to the battery. If the discharge is continued after the specific gravity has fallen below the lowest permissible limit, an excessive amount of lead sulphate is formed, which often causes the plates to buckle and is very difficult to remove. The lowest specific gravity reading to which battery should be discharged is, of course, given by subtracting the specific gravity range of the battery from the reading when the cell is fully charged.

At high rates of discharge, the residual capacity in the battery (before the minimum voltage is reached) may be somewhat less than the value calculated from the hydrometer readings. This is due to the abnormal potential drop at heavy discharge rates from local weakening of the electrolyte at the plate surfaces. When the discharge current is greater than that of the 9-hour rate, voltage measurements often give a better indication of the state of the battery than hydrometer readings. The following table shows, for various values of discharge current, the lowest permissible voltage to which a cell should be discharged.

Discharge Rate (hours)	Lowest Permissible Voltage per cell
5	1·79
6	1·8
7	1·81
8	1·82
9	1·83

Cadmium Testing. If on a test discharge, the capacity of a battery is found to be low, it is necessary to determine whether the positive plates, the negative plates, or both, are at fault. The condition of the plates can be examined by means of a cadmium test. The potential between both the positive and negative plates and the electrolyte varies with the state of discharge. It follows that any means of measuring the change of potential of the plates at a fixed rate of charge or discharge will give some indication of the capacity of the plates. If it were possible to place an auxiliary electrode in the cell which would maintain a constant potential with respect to the electrolyte, it would be possible to examine the

change of potential of the positive and negative plates separately throughout a charge or discharge cycle.

There are various materials suitable for auxiliary electrodes, but cadmium is probably the most extensively used substance. The greatest error in the use of the cadmium electrode occurs due to polarization, and this error is proportional to the potential being measured. The potential difference between the negative plate and the electrolyte is fairly low (from about 0·15 V to 0·25 V), but the potential of the positive plate is some ten times as great. The errors of polarization can, therefore, be minimized by measuring the potential between the negative plate and the cadmium electrode and by measuring the voltage at the cell terminals. The positive plate to cadmium voltage can then be calculated by adding together these two readings.

Fig. 592 shows typical results of a cadmium test during the discharge of a good cell. It will be noted that shortly after the commencement of the discharge, the cadmium to positive voltage reaches a fairly steady value of some 2·16 and this voltage is maintained until towards the end of the discharge when it commences to fall with ever increasing steepness. The voltage between the negative plate and the cadmium electrode rises gradually during the discharge period until it reaches a value of 0·2 V at the end of the discharge. If the cadmium to positive voltage falls more rapidly than is shown in Fig. 592, then it indicates a premature discharge (or lack of capacity) of the positive plates. If, on the other hand, the cadmium to negative voltage rises to a value of 0·2 V before the end of discharge, it indicates that there is insufficient capacity in the negative plates of the cell.

The cadmium electrode used for battery testing is made up in the form of a thin pencil mounted in a perforated tube of insulating material. It is supplied with a rubber covered lead for connexion to the voltmeter. Before a test is made, the cadmium electrode should be left to soak in the electrolyte for some minutes. (If the electrode is new or has not been used for some time it should be left to soak for about ½ hour.) The electrode should be immersed in the electrolyte at approximately the central position of the cell, and should be kept in one position for the duration of the test. The battery should be discharged at the 9-hour rate and ½-hourly cadmium to negative voltage readings should be taken after about the first 7 hours of discharge. The terminal p.d. of each cell should be taken at the same time as the cadmium to negative voltage. The results of the test can be plotted as a graph similar to Fig. 592.

As already stated, the negative plates may be considered to be exhausted when the cadmium to negative voltage rises to a value of 0·2. Conversely, the positive plate may be considered to be fully discharged when the cadmium to positive voltage falls to 2·0 V. As a result of these tests it is possible to determine whether the lack of capacity is primarily due to the negative or to the positive plates. If a battery has negative plates of insufficient capacity, the cell voltage may possibly be maintained due to an excess capacity of the positive plates. Alternatively, weak positive plates in conjunction with strong negative plates

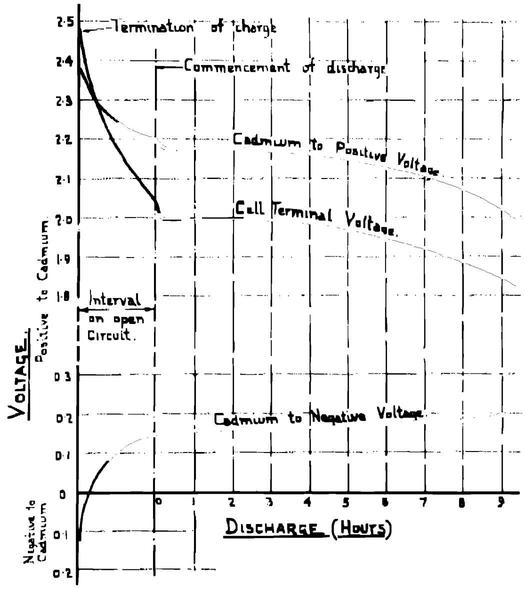


FIG. 592. TYPICAL CADMIUM READINGS DURING THE DISCHARGE OF A GOOD CELL

may give a normal terminal voltage. Generally speaking, a weak negative plate, in conjunction with a strong positive plate, is more detrimental than the reverse conditions. A weak positive may be due to insufficient forming and its strength may be built up by repeated charges. When the negative is weak, however, it is probably due to the loss of active material and further charging cycles will merely overwork the plate and shorten its life.

Faults and Defects of Secondary Cells. It is important that faults and defects in a secondary cell installation should be rectified as soon as possible in order to prevent permanent damage to the battery. The following are the more important defects encountered in practice:

Short Circuits. A short circuit can occur between the positive and negative plates of a cell due either

to *treeing* or *buckling* of the plates. Treeing is generally due to excessive gassing which tends to loosen the active material from the plates. The particles of active material fall into the electrolyte and may accumulate on the negative plates in such a way as to bridge the space between the positive and negative elements. If a short circuit is due to treeing, it can readily be removed by the use of a *scaling stick*. The scaling stick used in the Post Office is usually of ebonite, some 4½ to 5 ft. long and about $\frac{5}{16}$ in. thick. By the use of this stick, it is possible to explore the space between the positive and negative plates of a cell

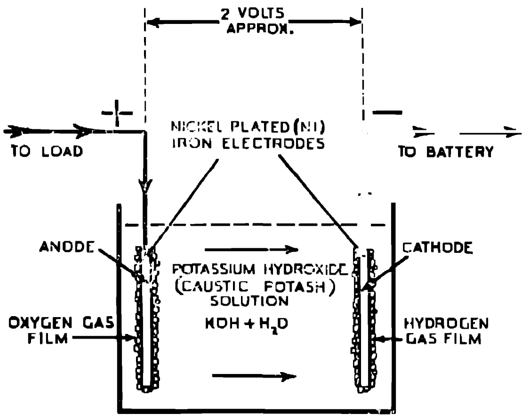


FIG. 593. PRINCIPLE OF ALKALINE COUNTER E.M.F. CELL

and to remove loose material or treeing. If the short circuit is due to buckling of the plates, it can be cured either by inserting additional separators or, in bad cases, by removing and straightening the plates mechanically.

After the short circuit has been removed, great care must be taken to restore the specific gravity of the electrolyte to normal by prolonged charging. Special low-voltage heavy-current booster sets are available for this purpose.

Sulphation. If a cell is given insufficient or infrequent charges or, alternatively, if a cell is over discharged, the lead sulphate undergoes a physical change and gradually turns into an obdurate form which is difficult to convert by charging. A cell in this condition is said to be *sulphated.* Sulphated cells can be recognized by the light colour of the plates and by the harsh and gritty surface. Such cells gas prematurely on charge and show a decreased capacity. If sulphation has been allowed to take place over a long time, it is difficult to rectify, but in some cases the cells can be restored to a good condition by charging for a prolonged period at a very low rate.

Corrosion. Corrosion is likely to occur in lead-acid cells, particularly at the bolted connexions between cells. This trouble can be avoided if all connexions between cells are kept tight and covered with a thin film of petroleum jelly. Sometimes the lugs of the cells corrode, and, if the corrosion is bad, it is necessary to burn on new lugs.

Decrease of Specific Gravity. After a cell has been in use for some years, there is a tendency for the specific gravity of the electrolyte to decrease. This reduction is due sometimes to the action of sediment at the bottom of the cells which abstract sulphuric acid from the electrolyte to form sulphates in the sediment. In other cases the lowering of specific gravity is due to loss of acid by spray during charging. Inadequate treatment after the removal of a short circuit may also result in a loss of specific gravity. On the other hand, extensive sulphation of the plates may be the cause of the trouble. If an examination of the cells shows that the loss of specific gravity is not due to the effects of short circuits or of sulphation, it is permissible exceptionally to add concentrated sulphuric acid to restore the specific gravity of the electrolyte.

Local Action. Local action between dissimilar metals on the surface of the plates may be caused by impurities either in the plates themselves or in the electrolyte. Normally, the loss due to local action is not greater than 1 or 2 per cent per day, and if the loss of capacity is greater than this value it is a sign of excessive local action. In some cases local action can be seen by the gassing of the negative plates when the cells are on open circuit. Renewal of the electrolyte may, in some cases, cure excessive local action.

Alkaline C.E.M.F. Cells. Lead-acid type cells are unsuitable for use as counter e.m.f. cells on automatic power plant except for very light loads. The passage of a current through such a cell promotes chemical reactions which "form" the plates in exactly the same way as the charging of a normal secondary cell. The lead-acid cell therefore stores an appreciable amount of energy and when it is desired to cut the c.e.m.f. cells out of the circuit, the switching contacts are required to stand the short-circuit current of the cells plus the exchange discharge current. Under such conditions the lead-acid c.e.m.f. cells and switching contacts would have a fairly short life.

The standard P.O. counter e.m.f. cells consist of nickel-plated iron electrodes immersed in a solution of caustic potash (potassium hydroxide). When a direct current is passed through any such electrolytic cell, hydrogen is released at the cathode and oxygen at the anode. Nickel is inert chemically to the action of these gases and hence no

chemical reactions occur at the electrodes. Instead, the gases very quickly cover the electrodes with a molecular film of gas. Any further passage of current merely generates more hydrogen at the cathode and more oxygen at anode; the gases rising to the surface and being dissipated in the surrounding air.

During operation, the unit thus becomes an electrolytic cell with electrodes of oxygen and hydrogen (Fig. 593). These two gases are well box, which is perforated to allow free circulation of the electrolyte. The whole plate assembly is supported from the ebonite lid of the cell. The lid is provided with a rubber gasket to ensure a good seating and the usual gas vent is fitted. All metal parts below the lid are nickel plated, but, in view of the fact that the cells are usually installed in the same room as lead-acid cells, all parts above the lid are lead-plated.

An electrolyte level gauge is provided to ensure

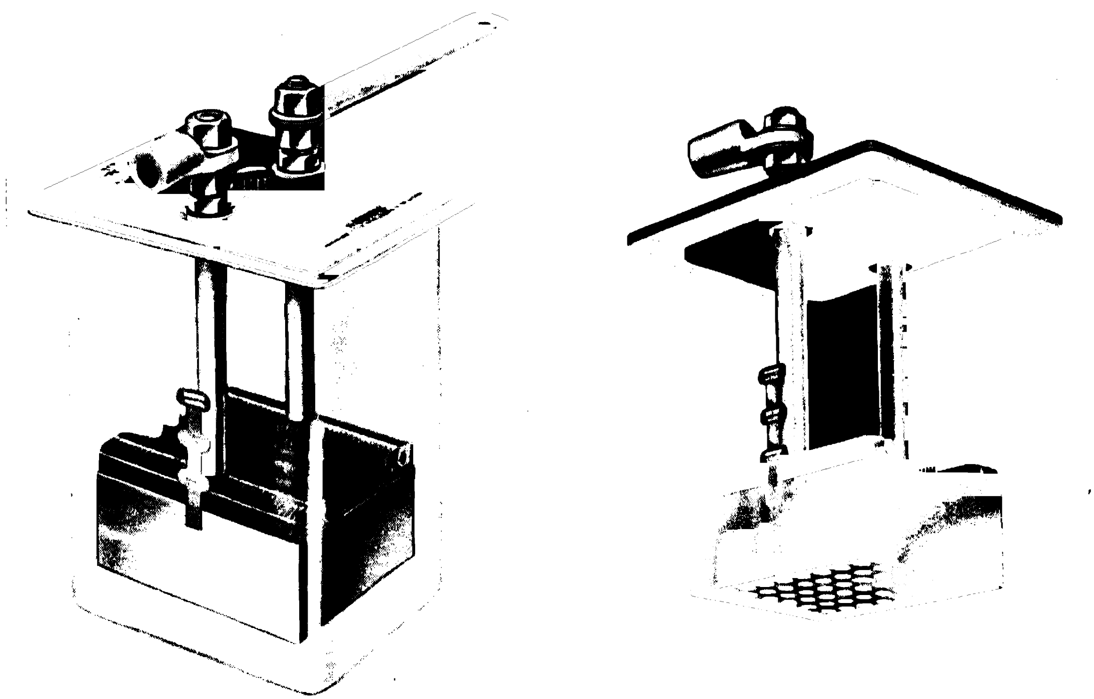


FIG. 594. CONSTRUCTION OF ALKALINE COUNTER E.M.F. CELL

separated on the electrochemical scale and produce a fairly constant back e.m.f. in the order of 2 V. The electrolyte must be such that it does not react chemically with the nickel electrodes, it must not change appreciably during the action of the cell, and it must have a reasonably low ohmic resistance. Either caustic soda or caustic potash are suitable, but the latter is adopted owing to its lower ohmic resistance. The electrolyte supplied is pure potassium hydroxide of 1·190 specific gravity.

Fig. 594 shows the general construction of the cell. The plates are assembled in a metal box open at the top and are provided with U-shaped ebonite spacers. The spacers rest on the bottom of the

that the electrolyte is kept within the required specific gravity limits. During the operation of the cell there is a vigorous agitation of the electrolyte, and to prevent loss through the vent plug a considerable space is left above the surface of the electrolyte. It is important that a naked flame should never be brought in the vicinity of these cells due to the presence of the hydrogen and oxygen which form an explosive mixture. It is also important to prevent grease or oil of any kind from coming into contact with the electrodes, since this would prevent the formation of the molecular gas film. Moreover, any oil in the electrolyte is emulsified by the action of the gases and forms a froth which may escape from

the vent plug. It is desirable never to handle the electrode assembly if this can possibly be avoided.

Fig. 595 shows the voltage characteristics of a c.e.m.f. cell when carrying various currents. It should be noted that when the current falls below about 10 per cent of the rated "maximum continuous load," the voltage of the cell falls rapidly and, due to the varying exchange current, becomes very erratic. Cells designed for a heavy current should therefore not be used on smaller installations without careful consideration.

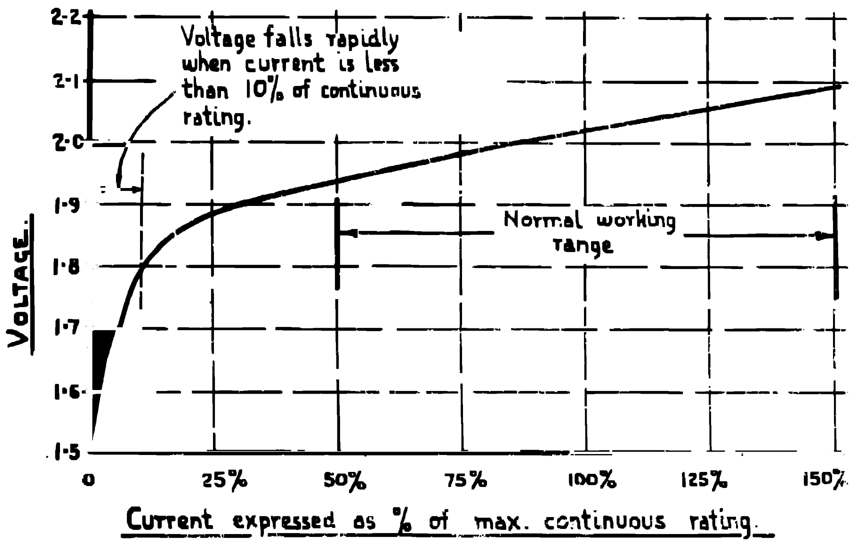


Fig. 595. Voltage Characteristics of Alkaline C.E.M.F. Cell

The NIFE alkaline c.e.m.f. cell must not be confused with the NIFE storage battery which is extensively used for a variety of applications such as electric traction, etc. The electrodes of the NIFE storage battery contain the active materials of nickel hydroxide for the anodes and cadmium oxide for the cathodes, the electrolyte being mainly a solution of potassium hydroxide. This type of cell is, of course, designed to have as large a capacity as possible.

Battery Room. The battery room of an exchange should be of ample size, and good ventilation is necessary owing to the acid spray and gases which pervade the atmosphere whilst charging is proceeding. In a confined space, these gases are explosive, and precautions must be taken to avoid the use of naked lights. The room should be cool (temperature of from 50° F. to 80° F.), it should be well lighted (preferably by daylight), and should have wall plugs fixed for the connexion of hand lamps. It is desirable that the windows should be frosted or painted where necessary to prevent the direct rays of the sun from falling upon the cells. Also, it is inadvisible to have Leclanché cells in the room owing to the ammonia liberated.

The cells are carried on a battery rack which is usually constructed of pinewood, varnished or painted with acid-resisting paint, and placed so that the edges of the plates can be inspected from both sides. The cells are insulated from the rack by means of rubber discs for the smaller cells or porcelain insulators with the large types (see Fig. 585).

The floor of the room should be of acid-proof asphalt tiles set in mastic cement, or, if a wooden floor, it should be covered with sheet lead. The battery room floor is often placed at a lower level than the floors of the adjacent rooms to which it gives access so that any escape of acid is restricted to the battery room. It is preferable that cells should not be placed in a room having a plaster ceiling.

Power for Telephone Exchanges. The electrical energy required for the operation of telephone equipment must be obtained in the first instance either from the public electricity mains or from a prime mover. This energy must be converted to direct current at a voltage suitable for charging the exchange batteries or, in the latest systems, for direct application to the exchange. Exchange power supply systems may be broadly divided into the following categories:

(*a*) Systems with d.c. generators driven by oil, petrol, or occasionally by gas engines.

(*b*) Systems with d.c. generators driven by a.c. or d.c. motors from the electricity supply mains.

(*c*) Systems in which direct current is obtained from a.c. mains via static rectifier equipment of the copper-oxide, selenium, thermionic valve, or mercury arc types.

(*d*) Systems where direct current is drawn from d.c. public supply mains.

Generally speaking, prime movers are provided only where public supply mains are not available or where the mains supply is known to be unreliable. Charging direct from the d.c. mains is

usually very uneconomical and is now rarely used except in a few cases where the demands are small and the mains voltage is low (say 110 V or less). In most cases where the mains are d.c., there is no practicable alternative to the use of motor-generator plant. A.c. supply mains are rapidly replacing d.c. distribution systems and permit the use either of static rectifying equipment or of generators driven by a.c. motors. There have been extensive developments during the past few years in the design of static rectifiers of the cupreous-oxide and selenium types. For small and medium size exchanges such rectifiers provide an efficient means of supplying power, whilst the absence of rotating plant minimizes the amount of maintenance attention necessary. Static rectifiers are, however, more expensive than motor-generator equipment when the demands are heavy and, in general, large generators driven by a.c. motors provide the most economical arrangement for large telephone exchanges.

Charging from D.C. Mains. Batteries can be charged from d.c. mains through a resistor of such a value that, with the required charging current, the potential drop across the resistor is equal to the difference between the mains voltage and the battery p.d. The method is normally too inefficient to be used regularly owing to the considerable power loss in the series resistance. If, for example, the average p.d. of a 20 cell exchange battery during charge is, say, 46 V and the mains voltage is 220 V, the power efficiency of the charging system is only about 21 per cent. The efficiency is somewhat higher when the mains voltage is lower (or the exchange voltage is higher) but there are extremely few cases where an efficiency comparable with that of a motor generator can be obtained. Under no circumstances should d.c. mains be connected to a battery which is serving the exchange.

D.C. Generator. Generators for battery charging are almost invariably of the shunt-wound type, i.e. with the field winding in parallel with the armature across the output terminals (Fig. 596). With this type of generator, the p.d. at the machine terminals is largely independent of the value of the output current and hence the machine is particularly suited to conditions where a reasonably steady p.d. is required over a wide range of load. The general form of the current/voltage characteristic of a shunt-wound generator is illustrated in Fig. 596. As the output is increased, the terminal p.d. decreases slightly due to the *IR* drop in the armature and distortion of the magnetic field resulting from the load current (armature reaction). This slight fall of p.d. is usually of no real disadvantage when the generator is used for battery charging. As the battery p.d. rises during charge, the current decreases, but the resulting increase in the voltage of the generator offsets, to some extent, the effect of the increased p.d. If the machine is used for floating across the exchange load, the slightly falling characteristic of the shunt-wound generator helps to stabilize the load on the machine as the current demand varies.

The output voltage of a shunt-wound generator can readily be adjusted over a wide range by means

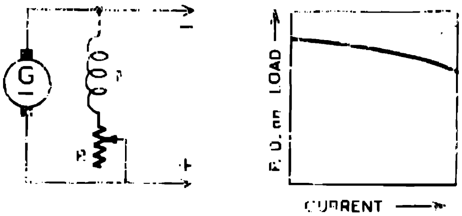


FIG. 596. CONNEXIONS AND VOLTAGE/LOAD CHARACTERISTICS OF A SHUNT-WOUND D.C. GENERATOR

of a resistance (*R*) in series with the field windings (Fig. 596). With the field rheostat set at the position of minimum resistance, the current through the field coils and the flux-density in the armature air gaps are a maximum. Thus, the maximum e.m.f. is generated. As resistance is introduced into the field circuit, the magnetic field strength is reduced and the e.m.f. generated at a given driving speed is consequently lower.

Generators with series connected field coils are never used for telephone work. Such generators are unstable under conditions where the output load may vary. Moreover, when a battery is included in the output circuit of a series generator there is a danger of a very heavy discharge through the machine. This does not apply when shunt-wound generators are employed for, if the generator p.d. falls below that of the battery during charging (and the protective devices fail to operate), the battery will merely drive the generator as a motor with the same direction of rotation.

The Dynamotor. The dynamotor is a combined generator and d.c. motor. The two parts of the machine (the motor and the generator) are arranged with a common field system but with an armature which has two distinct windings each with its own commutator. The dynamotor provides an economical means of supplying current for battery charging from d.c. mains when the required output is small. The method of construction is such that it is not suitable for high outputs. Usually the output voltage of a dynamotor is regulated by altering the position of the generator brushes.

Some machines are fitted with a *compensator* which consists of an iron wire resistor connected in series with the output. This resistor has a high positive temperature coefficient and hence its resistance increases with the value of the charging current. As the charging current from the dynamotor falls, due to the increased back e.m.f. of the battery during charge, the temperature and resistance of the iron wire compensator decrease and so tend to minimize the fall of current towards the end of the charge.

D.C. Motors. When the public electricity supply is d.c., the only practicable method of driving a generator is by means of a shunt-wound d.c. motor. With this type of machine, the armature coils are connected to commutator segments and the armature current is supplied from the mains via suitable brush gear. The winding is in shunt with the armature so that, when the machine is fully running, the armature and field are both in parallel across the mains. The speed of a shunt-wound motor (at constant mains voltage) decreases very slightly as the load is increased (Fig. 597). The characteristic is, however, fairly flat and this type of machine is eminently suitable for driving a generator where a uniform speed is required at widely different load values. A series connected motor is quite unsuitable for a motor-generator set owing to the wide variation of speed at various values of load. Moreover, if the load is completely removed from a series motor, there is a risk that the speed will increase to a dangerous value.

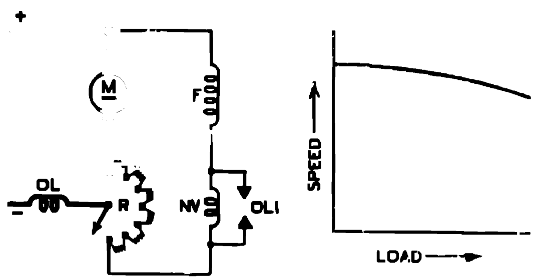


FIG. 597. CONNEXIONS AND SPEED/LOAD CHARACTERISTICS OF A SHUNT-WOUND D.C MOTOR

The armature of a d.c. motor has, by design, a low ohmic resistance in order to minimize the copper losses (I^2R) in the armature. If, on starting the motor, the mains were applied direct to the armature, the current would be excessive and it is therefore necessary to make special arrangements for starting the machine. The usual motor starter is connected as shown in Fig. 597. The starter consists of a spring restored rheostat (R) which inserts a resistance in series with the armature on starting. The rheostat arm is moved slowly from stud to stud and, as the motor gains speed, the back e.m.f. generated limits the value of the current through the armature. Arrangements must be made in the starter to prevent the application of the full mains voltage to a machine at rest. The motor starter is so arranged that the starter arm is held in the running position by means of a no-volt electromagnet (NV) which is energized from the mains in series with the field coils. If the mains should fail, then the starting rheostat arm is automatically released. If the speed of the motor is reduced due to an excessive load, an overload electromagnet (OL) operates to release the starter arm. It will be noted that the starter circuit is so arranged that it is not possible to disconnect the field circuit at any time during the starting or stopping of a motor. If such a disconnexion were allowed, there would be a danger of very high voltages in the highly inductive field system.

A.C. Motors. A.c. public supply mains are now rapidly replacing the earlier d.c. systems. The a.c. motors associated with exchange motor-generator sets are mainly of the induction type. Some very small induction motors are of the single phase type but, generally speaking, 3-phase machines are installed. Small induction motors are often of squirrel cage construction, i.e. with heavy copper bars instead of rotor windings. No special starting arrangements are normally required for such machines, and the full mains voltage is applied to the stator windings at starting. Larger squirrel cage motors are normally started by applying a reduced voltage to the stator windings. This lower voltage may be obtained by means of an auto-transformer or sometimes by connecting the field windings in a *star* arrangement at starting, and in the *mesh* formation for normal running. For reasons which are beyond the scope of this volume, the performance at starting of the squirrel cage type of induction motor is rather poor.

Most medium and large size induction motors have polyphase (normally 3-phase) rotor windings. The windings may be connected either in the star or mesh arrangement, and the leads are brought out to slip rings. The slip rings are connected via low resistance brushes to a starting resistor. The resistance is cut out step by step as the motor gains speed, and ultimately is entirely cut out and the slip rings are short-circuited. In the larger machines, it is common practice to provide a changeover switch so that, when the machine is running at full speed, the rotor coils are short-circuited by means of a special rotating switching device, and the brushes are lifted from the slip

rings in order to minimize the frictional losses, brush contact resistance, brush and slip ring wear, and so on.

The speed/torque characteristic of an induction motor is somewhat as illustrated in Fig. 598. As the speed increases, the torque also increases until at a certain critical value the maximum torque is passed and any further increase of speed gives a progressively lower and lower value of torque. In practice, the speed of an induction motor

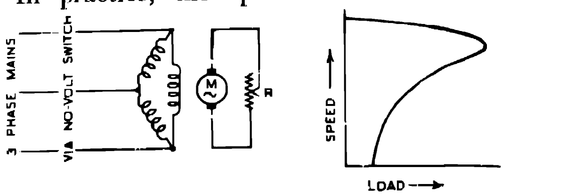


FIG. 598. CONNEXIONS AND SPEED/LOAD CHARACTERISTICS OF A 3-PHASE INDUCTION MOTOR

decreases slightly as the load increases, but beyond a certain critical value of load the machine will stop and will not re-start until the load is removed. The most important disadvantage of the polyphase induction motor is the low power factor, particularly at light loads. Although the power factor may be reasonably high at full load, it is almost always very low when the machine is running light.

Synchronous motors are occasionally used for very large motor generator sets. The synchronous motor has a better power factor than the induction motor—(in fact, the power factor can be made of any value within certain limits). On the other hand, the synchronous motor requires an auxiliary d.c. generator to excite the field, and special arrangements must be made for starting and synchronizing. The synchronous motor must of necessity run at constant speed irrespective of the load. As in the case of the induction motor, the machine will stall if the load exceeds a certain critical value.

Prime Mover Generator Sets. Engine-driven generator sets are utilized in circumstances where public supply mains are not available and also in other circumstances to provide a safeguard against failure of the public supply. There are a wide variety of engine-driven generator sets of the stationary type. In some of the smaller sets single cylinder 2-stroke petrol engines of robust design are fitted. In larger installations, large stationary diesel engines may be used. In nearly all cases constancy of speed is obtained by means of mechanical governors which regulate the fuel supply to the engine. In some cases arrangements are made for the automatic starting or stopping of the machine as required.

Emergency Generating Sets. It has already been mentioned that emergency engine-driven generating sets are provided at strategic centres for use at any exchange where a prolonged mains failure threatens the continuity of the service. There are numerous types of emergency sets, but, broadly speaking, they can be divided into:

(*a*) Sets which generate d.c. at a voltage suitable for battery charging.

(*b*) Sets which generate a.c. at the normal mains voltage.

One common emergency generating set of the d.c. type consists of a 100 h.p. 4-cylinder water-cooled diesel engine, which is mounted on a road chassis so that it can be towed behind a suitable vehicle. The generator of this particular set is of the pipe-ventilated shunt-wound type and is directly coupled to the engine. The generator has a nominal output of 1000 A at 67 V, but a voltage range of from 24 to 80 V is obtainable by means of a field rheostat and by varying the engine speed. The unit includes a switchboard with all the necessary switches, voltmeters, circuit breakers, etc.

Amongst the a.c. emergency generating sets is a 5 kW 3-phase unit. The engine is a 14 h.p. 4-cylinder water-cooled petrol engine, which is directly coupled to a 4-pole, self-excited alternator. The alternator has an output of 400 V 3-phase at a frequency of 50 c/s. The same generator also enables a supply or 230 V to be obtained between one phase and neutral.

Some emergency generating sets are capable of providing either d.c. or a.c. as required. The 6 kW

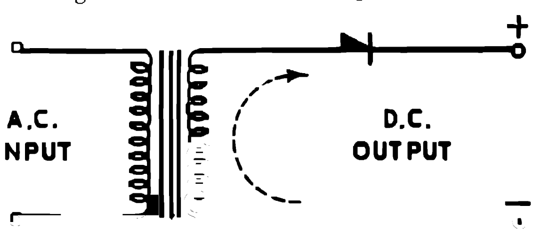


FIG. 599. HALF-WAVE RECTIFIER CIRCUIT

emergency d.c./a.c. set is mounted on a road chassis with a 12 h.p. 4-cylinder petrol engine directly coupled to a generator which can be arranged to give either a direct current of 105 A at 75 V, or a single phase alternating current at 200–250 V.

Static Rectifiers. If an a.c. public supply is available, static rectifiers of the metal, thermionic or mercury arc types may provide an economic means of supplying direct current at low voltage. A rectifier is essentially a device which offers a

low impedance when subject to a voltage in one direction, but behaves as a high impedance when the polarity of the applied voltage is reversed. Fig. 599 shows possibly the simplest form of rectifier circuit. The a.c. mains are applied to the primary of a transformer so designed that the secondary voltage is of the required value. The rectifier is connected in series with the secondary winding, so that current flows in the secondary circuit each alternate half cycle. The effect is shown diagrammatically in Fig. 600, from which it will be noted that there is one pulse of unidirectional current in the output circuit for each positive half-cycle of the applied a.c. The negative half-cycle of the applied e.m.f. is entirely suppressed, and hence this simple circuit is often known as a *half-wave rectifier*. Whilst a half-wave rectifier is reasonably satisfactory for charging a battery, it is not very suitable for use in circumstances when the rectifier output may be required to serve the exchange direct. Under these conditions a very considerable degree of smoothing would be necessary before the rectifier output could be used.

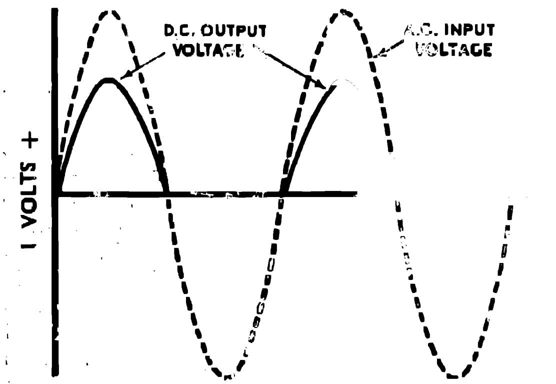


FIG. 600. OUTPUT VOLTAGE OF HALF-WAVE RECTIFIER

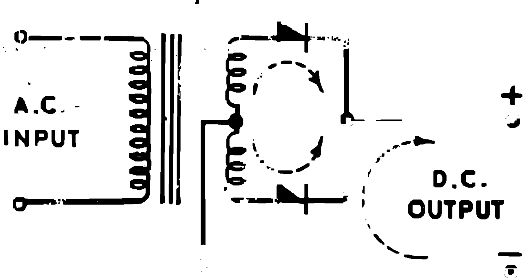


FIG. 601. FULL-WAVE RECTIFIER WITH CENTRE TAPPED TRANSFORMER

Fig. 601 shows a development to give full-wave rectification of the alternating current. In this circuit a transformer with a centre tapped secondary winding is employed, and the two rectifiers are so connected that current flows through the rectifiers in turn during consecutive half-cycles. The d.c. voltage output of a full-wave rectifier is shown in Fig. 602. There are now two surges of current in the secondary circuit for each cycle of the applied a.c., and hence the output fluctuates at twice the frequency of the mains supply. It will be observed that the R.M.S. value of the fluctuating unidirectional voltage is much greater when the full-wave rectifier is employed than when half-wave rectification is used.

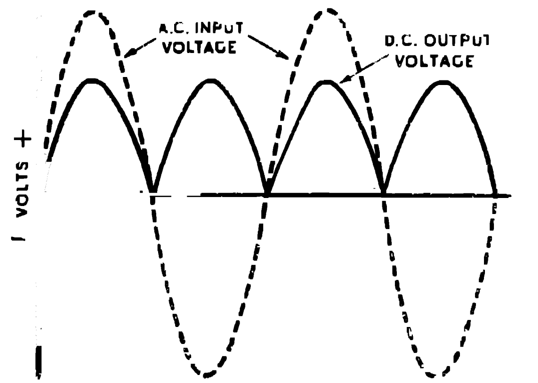


FIG. 602. OUTPUT VOLTAGE OF FULL-WAVE RECTIFIER

Fig. 603 shows an alternative method of obtaining full-wave rectification by means of a "bridge network" of rectifiers. In this circuit the secondary of the transformer has no centre tap, but the rectifiers are so connected that there is a unidirectional voltage across the centre points of the rectifier network.

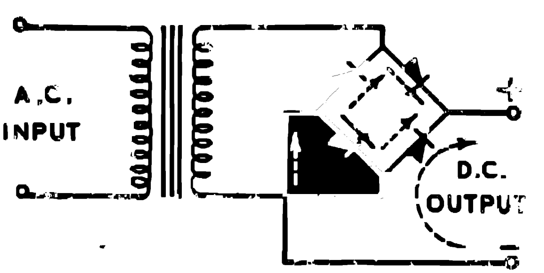


FIG. 603. FULL-WAVE BRIDGE CONNECTED RECTIFIER

A considerably smoother output can be obtained by the full-wave rectification of a 3-phase supply (Fig. 604). As before, the output from each phase fluctuates at a frequency twice that of the mains, but when the outputs of the 3 phases are combined it produces a d.c. output which has a ripple

frequency six times that of the supply mains. Thus, by the use of a full-wave rectification on a 3-phase supply, it is possible to obtain a d.c. output which has a comparatively small ripple voltage which can readily be smoothed out.

Metal Rectifiers. Rectifiers of the metal or dry plate type are becoming increasingly used for producing a d.c. power supply from a.c. mains. The rectifiers are of two main types, i.e. copper oxide rectifiers and selenium rectifiers. The electrical characteristics of each type have already

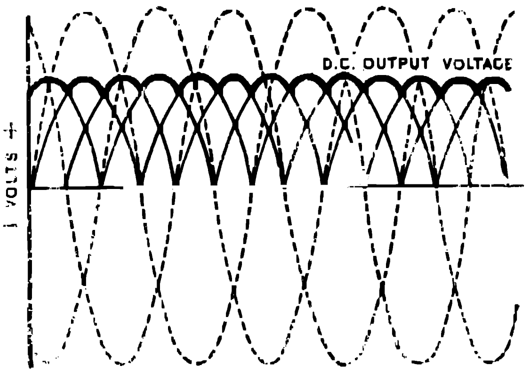


FIG. 604. OUTPUT VOLTAGE OF 3-PHASE FULL-WAVE RECTIFIER

been considered in Chapter IV. The rectifiers used in power circuits are invariably fitted with cooling vanes between the rectifier elements to assist in the dissipation of heat. It has been seen (Figs. 50 and 54) that overloading of a metal rectifier materially reduces the efficiency of the unit and may result in complete breakdown. Overloading may occur due to the passage of an excessive current in the conducting direction, or to an excessive p.d. across the rectifier in the non-conducting direction. (The I^2R value is the governing factor in each case.) The following table gives typical characteristics of rectifier elements of the selenium and copper-oxide types.

Type	Diameter of element (cm)	Cooling fins	Maximum rectified current (mA)	Maximum reverse volts per element
Copper oxide	1·91	No	50	6
Copper oxide	1·91	Yes	150	6
Copper oxide	3·81	Yes	500	6
Selenium	1·8	Yes	40	18
Selenium	4·5	Yes	300	18
Selenium	11·2	Yes	2000	14

Power rectifiers using copper-oxide or selenium elements are mostly of the full-wave bridge type (see Fig. 603). The elements are assembled in various series and parallel arrangements in order

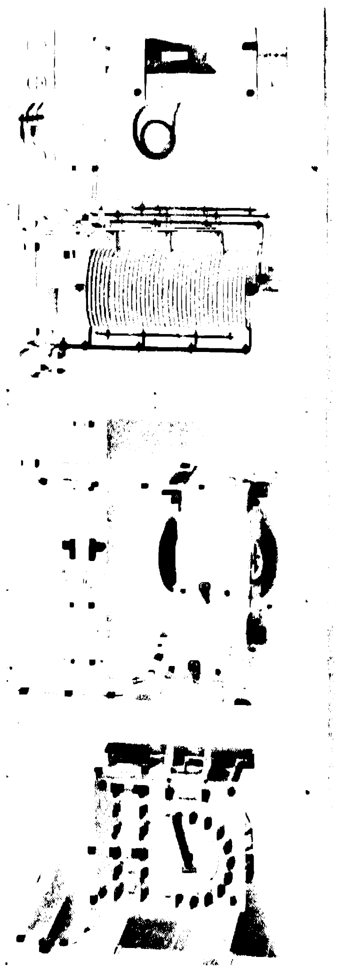


FIG. 605. TYPICAL METAL RECTIFIER UNIT (Rectifier No. 47E)

to meet the specified current and voltage requirements. In order to obtain the maximum cooling effect, the rectifiers are so arranged that the cooling fins are in a vertical plane, and the outer case is provided with slots or grids to ensure adequate ventilation. There are a large number of standard

rectifiers to meet various conditions. Fig. 605 shows a typical unit (Rectifier No. 47E) which gives an output of up to 20 A at a p.d. of 50 V. This particular rectifier contains smoothing equipment so that the unit can be used directly without auxiliary equipment for floating across an exchange battery. The mains transformer with its adjustable toppings is placed at the bottom of the cubicle whilst the output smoothing choke occupies the centre position. The rectifiers are (in this instance) of the selenium type with circular cooling vanes, and a semi-variable resistor at the top of the unit, allows the value of the output current to be regulated.

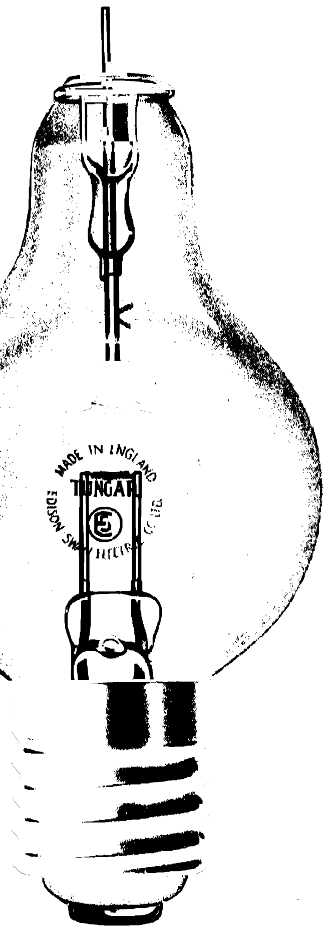


FIG. 606. "TUNGAR" RECTIFIER

Tungar Rectifiers. The Tungar rectifier is fundamentally a 2-electrode electronic valve of low impedance. The rectifier tube (Fig. 606) has a Tungsten wire filament which is taken out to an Edison screw cap, whilst the anode is a graphite disc led to a terminal at the top of the bulb. The air is exhausted from the tube and a small quantity of some inert gas—usually argon—is introduced. When the filament is heated it emits electrons which are attracted to the higher potential anode. In passing through the space between the two electrodes, the electrons collide with the gas molecules and ionize them, thereby forming a conducting path from the anode to the filament. If, however, the anode is at a negative potential relative to the filament, the electrons emitted by the filament are attracted back again. Under these conditions the valve remains non-conductive. The presence of the argon gas limits the voltage which

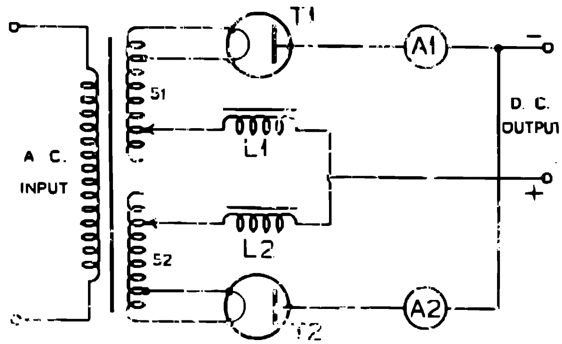


FIG. 607. CIRCUIT OF A 2-BULB TUNGAR RECTIFIER

can be applied to the anode, and with the normal type of bulb, any anode voltage in excess of about 90 V is liable to produce a "flashover." The bulbs have a guaranteed life of 600 hours provided that they are correctly used.

Fig. 607 shows a typical Tungar rectifier circuit utilizing two bulbs ($T1$ and $T2$) to give full-wave rectification. A separate regulating switch is provided to control the voltage applied to each anode by the selection of suitable tappings on the mains transformer. Iron cored inductances $L1$ and $L2$ are included in the anode circuit of each valve to smooth out the voltage ripples. Separate ammeters ($A1$ and $A2$) are provided so that the load on the two tubes can be equalized. The maximum loading per bulb is in the order of 6 A, so that a 2-bulb rectifier unit can be used to give a total output of some 12 A. The overall efficiency of a Tungar rectifier is somewhat low (approximately 55 to 65 per cent)—due primarily to the voltage drop in the tubes themselves.

Mercury Arc Rectifiers. The mercury arc rectifier has been used for many years as a means of producing a direct current of fairly large magnitude from a.c. mains. Mercury arc rectifiers may be

either of the glass bulb type or, in the larger units, the rectifier may be housed in a steel container from which the air is continuously evacuated. Fig. 608 shows a typical mercury arc rectifier circuit of the type used in exchange power plants. For simplicity a single phase full-wave rectifier is shown, but the arrangements of 3- or 6-phase rectifiers follow the same general principles. The rectifier proper consists of a large glass bulb, from which the air has been exhausted. A pool of mercury (the cathode) is introduced into the bottom of the bulb, and the circuit is so arranged that an arc is formed between the pool of mercury and certain electrodes (the anodes) in the upper portion of the tube. The arc so formed has the characteristic that it will conduct from the anode to the mercury cathode, but not vice versa.

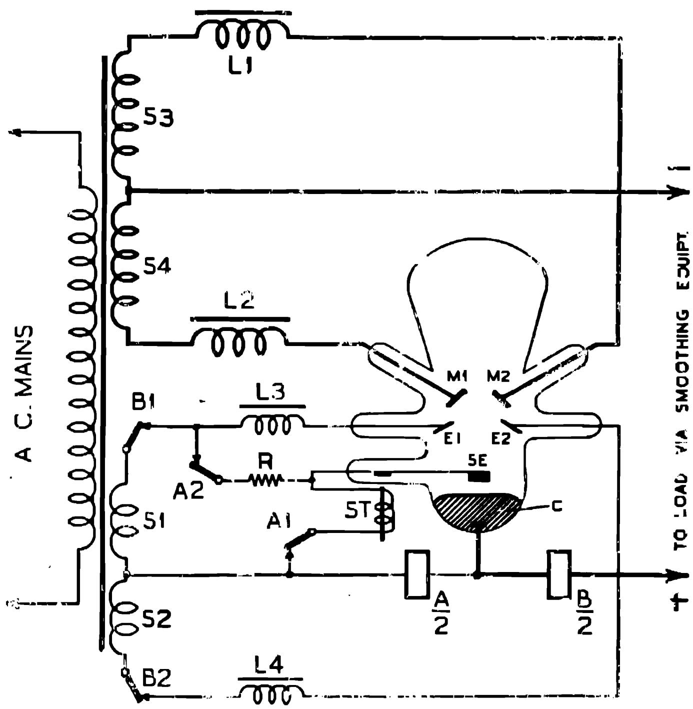


FIG. 608. SINGLE PHASE MERCURY ARC RECTIFIER

When the mains are connected to the primary winding of the transformer, the a.c. voltage induced in the secondary winding $S1$ causes a current to flow through the starting magnet ST. This magnet is placed outside the bulb but immediately below the flexibly mounted starting electrode SE. Energization of the magnet causes the starting electrode to dip into the pool of mercury, and the circuit so completed allows current to flow through relay A. The operation of contacts **A1** and **A2** disconnects the circuit of the starting electromagnet, so that the starting electrode is released from contact with the pool of mercury. As the starting electrode leaves the mercury, an arc is formed which is maintained due to the voltage on the exciter electrodes $E1$ and $E2$. The main secondary windings ($S3$ and $S4$) of the transformer are connected to the electrodes $M1$ and $M2$ and, when the external d.c. circuit is completed, the voltage on these main electrodes extends the arc and thereby allows a unidirectional current to flow round the output circuit. A second relay B is included in the output circuit and is so arranged that its contacts **B1** and **B2** disconnect the starting and exciter electrodes to prevent an unnecessary waste of energy. If, at any time, the output circuit is disconnected, relay B releases and, by applying the potentials to the exciter electrodes $E1$ and $E2$, maintains the arc until such time as the external load is reapplied.

It is customary to introduce inductance coils $L1$, $L2$, $L3$, and $L4$ to assist in the maintenance of the arc and to minimize the possibility of surge currents through the rectifier. The efficiency of a mercury arc rectifier depends to a large extent upon the output voltage required. High voltage mercury arc rectifiers may have a power efficiency as high as 95 per cent, but on telephone exchange type rectifiers (where a direct current at a comparatively low voltage is required) the efficiency seldom exceeds 60 to 65 per cent. The comparatively poor efficiency at low voltages is due primarily to the potential drop (about 12 V in all) at the electrodes This voltage is substantially independent of the current delivered by the rectifier. The power losses introduced by this potential drop are of little consequence when the output voltage is high, but as the voltage is reduced the I^2R losses at the electrodes form a progressively greater proportion of the total power.

Most of the mercury arc rectifiers used in telephone exchange power plants are of the glass bulb variety with a rated capacity of 35 A. Several rectifiers are placed in parallel if a greater output is required.

Smoothing Equipment. The voltage of a direct current generator is not absolutely steady, but rises and falls by a small amount at a frequency depending upon the physical construction (e.g.

the number of armature slots, etc.) and speed of the machine. If such a machine were to be used for floating across a battery at a telephone exchange, it would give rise to an annoying hum in the receivers of the telephones. It has been seen that the direct current output of static rectifiers also contains an appreciable "ripple voltage." If the installation is such that the rectifiers or generators may be floated across the working exchange battery, it is necessary to provide some means of smoothing out the voltage ripples.

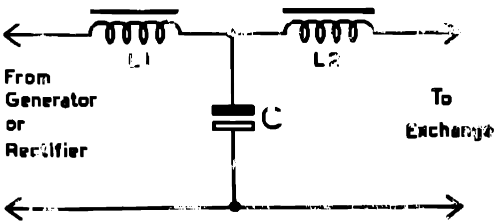


FIG. 609. SINGLE T-SECTION SMOOTHING FILTER

The maximum permissible ripple voltage depends to a large extent upon the frequency of the ripple. For example, a very small ripple voltage at a frequency of 1000 c/s would probably cause a greater disturbance to the transmission efficiency of an exchange than a very much larger ripple voltage at, say, 50 c/s. In order to make allowance for this, a special instrument known as a *psophometer* has been developed for the measurement of disturbance voltages. The instrument is fundamentally an a.c. voltmeter with an electrical network which "weights" the reading to correspond with the sensitivity of the telephone receiver and of the human ear itself. The *psophometric voltage* obtained is therefore a measure of the disturbing effect as observed by a telephone subscriber. The specification for exchange power plants lays down that the psophometric voltage of a generator or rectifier set when measured at the exchange busbars shall not exceed 1 mV.

The ripple voltage from a d.c. generator can be minimized by careful attention to machine design, by providing a large number of poles and commutator segments, and by properly shaping the pole tips. Such special design does, however, increase the cost of the machine, and there is some reduction in efficiency. Modern practice favours the use of generators of standard commercial design in conjunction with a smoothing circuit. The most common type of smoothing circuit consists of a single stage T-section filter as shown in Fig. 609. The two chokes $L1$ and $L2$ are in series with the supply circuit and offer a high impedance to any fluctuating currents The chokes are usually wound on cores of silicon steel, and the conductor size must be adequate to carry the maximum current without undue voltage drop. A bank of electrolytic condensers (C) is connected to the centre point of the two chokes in order to assist in the smoothing. The electrolytic condenser bank may vary in capacity from, say, 100 μF up to a maximum of some 30 000 μF. Large electrolytic condenser banks are made up of a series of separate condensers in parallel so that the capacity of each condenser does not exceed 4000 μF. Fuses are inserted in series with the condensers to guard against the risk of fire should one or more of the condenser units break down in service.

Power Switchboard. The various batteries, generators, rectifiers, etc., of an exchange power plant are all connected to a *power switchboard* which accommodates the switches, meters, and other apparatus necessary for the control of the power supply to the exchange. The early power switchboards (or power boards) were made up of highly polished slate panels, but modern

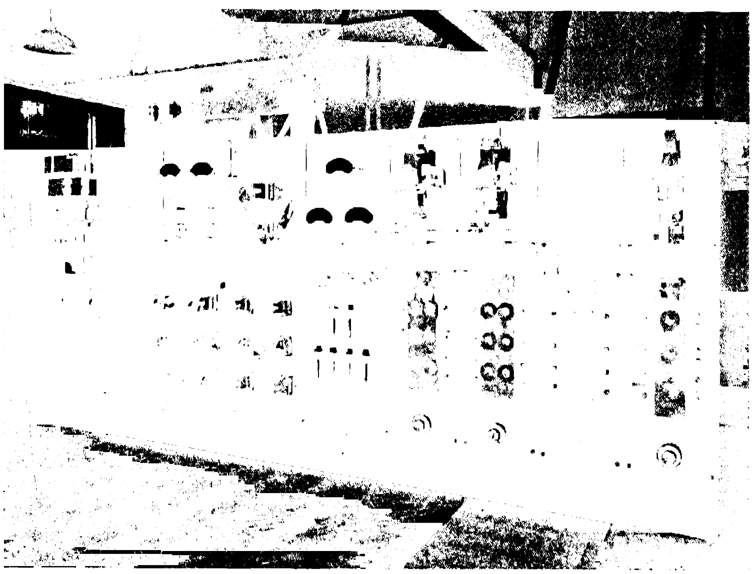


FIG. 610. GENERAL VIEW OF POWER BOARD ARRANGED FOR CHARGE-DISCHARGE WORKING

practice favours the use of ebony sindanyo with a black enamel finish. The positive poles of both main batteries and of all the generators or rectifiers are connected to a common earth bar, and switching is effected on the negative leads by means of single-pole knife switches. The arrangement of these switches depends upon the type of power plant (i.e. charge-discharge working, or a float system). Where the switching scheme provides for two batteries to be connected alternately to the exchange, it is necessary that the knife switches should be of the make-before-break type in order to prevent interruption of the supply.

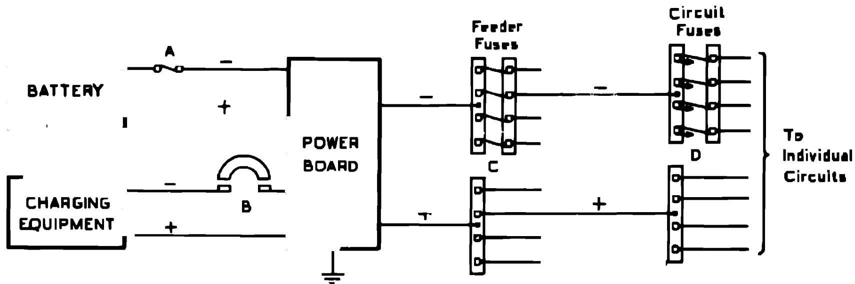


Fig. 611. General Arrangements of Exchange Power Distribution

The power board contains the voltmeters and ammeters necessary for the measurement of the various voltages and currents. In most installations, the same meter is required for the measurement of the current or voltage at various parts of the circuit, and rotary switches are provided to effect the desired switching.

Fig. 610 shows a typical power switchboard at a large exchange where charge-discharge working is in use. The general circuit arrangements of the switchboard are considered later in Fig. 616.

Power Distribution. A typical telephone exchange power distribution system is shown diagrammatically in Fig. 611. The batteries are cabled as a loop circuit to the power board and a fuse (A) of suitable size is connected in the negative lead as near as possible to the battery terminal. The charging equipment is cabled in a similar way to the power board and protection is provided by an overload circuit breaker (B) which is usually located on the power board. When motor-generator sets are used for charging, this circuit breaker also incorporates a reverse current feature to prevent the battery driving the generator in the event of a mains failure. If a short-circuit fault occurs on the charging equipment side of the circuit breaker, the load would be such that a motor-driven generating set would shut down. Rectifier equipment is fused for such a contingency.

The positive lead of the discharge circuit is connected to the earth at the power board which is extended from the M.D.F. In small and medium size manual exchanges the battery leads of all the various circuits are wired to a common *fuse board* (D) for the exchange and the busbars of this fuse board are cabled back to the power board. In larger exchanges (particularly where the apparatus is spread over several floors) it is inconvenient and uneconomical to serve the whole exchange from one centralized fuse board. In such cases there may be a number of fuse boards each served by a large capacity feeder fuse (C).

The power distribution arrangements of an automatic exchange are considered in Vol. II, but it may be mentioned at this stage that modern practice favours the location of the circuit fuses on the apparatus racks with a system of busbars to supply the power to the various suites of racks. It is convenient, with this system, to locate the feeder fuses at convenient points on the main busbar run.

Circuit Breakers. Where the power supply for an exchange is provided by means of motor generators, it is important to guard against:

(a) an excessive current which would damage the generators, and

(b) the discharge of the battery through the generator should the voltage of the latter fall below that of the battery.

The use of fuses as a protection against overload is not satisfactory under these conditions, owing to the possible necessity of frequent replacement. Fuses do not, moreover, provide any safeguard against a reversal of current in the charging circuit (condition (b)). Complete protection is in practice provided by the use of circuit breakers in the charging circuit. A circuit breaker is essentially a manually operated switch which locks mechanically after operation under the control of an electromagnet known as a *trip coil.* Circuit breakers may provide protection against overload only, or may be so designed that they will disconnect the charging circuit either on overload or when the current in the charging circuit is reversed.

There are numerous types of circuit breaker. In some designs the main charging current is passed through the trip coil and the mechanism is so adjusted that the trip coil armature is attracted

when the current exceeds a predetermined value. The reverse current release feature is, in some designs, also included in the circuit breaker assembly by providing a reverse current coil to polarize the magnetic circuit of the overload coil. Modern practice favours the use of separate overload and reverse current relays on circuit breakers for large installations. Fig. 612 shows the prin-

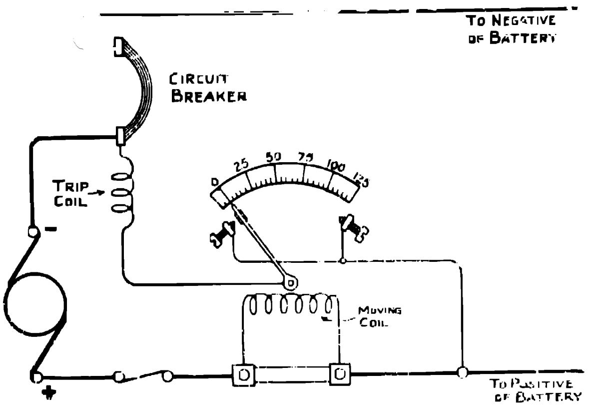


Fig. 612. Circuit Breaker with Separate Overload and Reverse Current Relay

ciple of a typical circuit breaker with a separate overload and reverse current relay. The relay in this case is constructed in the form of a moving coil ammeter which is provided with contacts so that the trip coil of the circuit breaker is energized if the current either exceeds a predetermined value or is reversed in direction.

Precautions must be taken in the design of a circuit breaker to prevent the formation of an arc when the breaker releases. It is usual to provide auxiliary carbon contacts which are arranged to open after the main contacts of the circuit breaker. By this means the high resistance of the carbon electrodes reduces the value of the current before complete interruption of the circuit. In addition, large circuit breakers are sometimes provided with "blow-out" coils, i.e. a powerful electromagnet is so arranged that any arc which forms between the opening contacts is extended by the magnetic field and rapidly extinguished. Circuit breakers are so designed that a quick make of the contacts is obtained on operation, and a rapid opening of the contacts on release.

Fuses. A telephone exchange is composed of a large number of individual circuits, and the normal current in each circuit is very small. Small gauge wire can therefore be used for the power supply to these circuits but, in order to protect this wiring, a very large number of circuit fuses are required. In addition to the circuit fuses, a number of large capacity main distribution and feeder fuses are required at various parts of the exchange.

There are two main types of fuse, i.e. enclosed or *cartridge fuses* for the main distribution system, and *alarm type fuses* for the individual circuit protection. Fig. 613 shows a typical distribution fuse of the cartridge type. The fuse wire is contained in a sealed tube of non-inflammable paste-board filled with some highly refractory non-conducting powder, such as French chalk, which prevents the formation of an arc when the fuse blows. The fuse is provided with spade type terminals for connexion to the busbars of the fuse panel. A paper label round the centre portion of the fuse indicates the maximum permissible voltage of the circuit, the rating current and the fusing current. A secondary fuse of very fine wire is connected in parallel with the main fuse and the subsidiary fuse is looped through holes in the cartridge and passes under the paper label. When the main fuse blows due to excessive current, the secondary fuse also blows, and in doing so chars the white paper label, thereby giving a visual indication that the fuse has operated. Cartridge fuses are available in capacities ranging from 3·0 to 500 A (rating current). Sometimes two 500 A fuses are connected in parallel where a rating current of 1000 A is required, but it is generally inadvisible to parallel

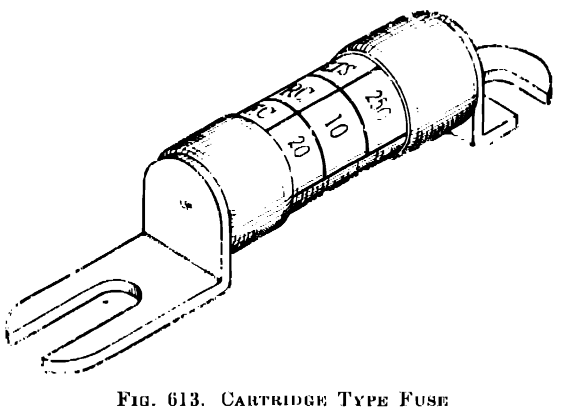


Fig. 613. Cartridge Type Fuse

more than two fuses on account of the difficulties of obtaining a uniform distribution of current. In cases where a protective device is required to carry a normal current of more than 1000 A, it is usual to install overload circuit breakers.

The alarm type of fuse, which is used for the protection of individual circuits, is illustrated in Fig. 614. The fuse wire is held in tension between

two springs which are so arranged that, when the fuse wire melts, the lower alarm spring makes contact with an alarm bar in the fuse mounting, whilst the upper spring stands out prominently from the fuse mounting. A coloured bead, fixed to the upper spring, gives a clear indication of

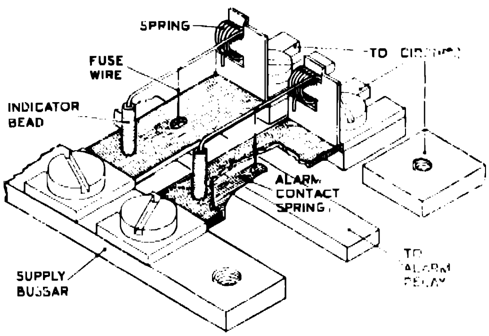


FIG. 614. ALARM TYPE FUSES

the location of a blown fuse. It is important that alarm type fuses should be connected the right way round in order that the battery busbar shall be connected to the alarm bar when the fuse blows. The shape and size of the slots in the fuse are such that it is in practice impossible to insert the fuse incorrectly. Alarm fuses are available in four different capacities, the capacity of the fuse in each case being indicated by the colour of the bead. The Post Office code, the rated current, and the colours of the beads are as follows:

Code	Rated Current	Colour of Bead
31/1	0·5	Blue
31/1A	1·0	Yellow
31/2	1·5	Red
31/3	3·0	Black

In some cases it is desirable that an alarm should be given when a main feeder fuse of the cartridge type operates. It is usual, in such circumstances, to connect an alarm fuse in parallel with the cartridge fuse, so that an audible alarm is given if the fuse blows. In these circumstances, there is a possibility (in inductive circuits) of a considerable voltage across the alarm fuse at the moment the circuit is disconnected. The standard alarm type of fuse has been found quite satisfactory, even under very adverse conditions, and there is no tendency for an arc to form.

Charge-discharge Schemes. A simple charge-discharge power circuit is shown in Fig. 615. The meter connexions and auxiliary supplies have been omitted for simplicity. Provision is made to measure the voltage of either battery and of the generators before the circuit breaker is closed.

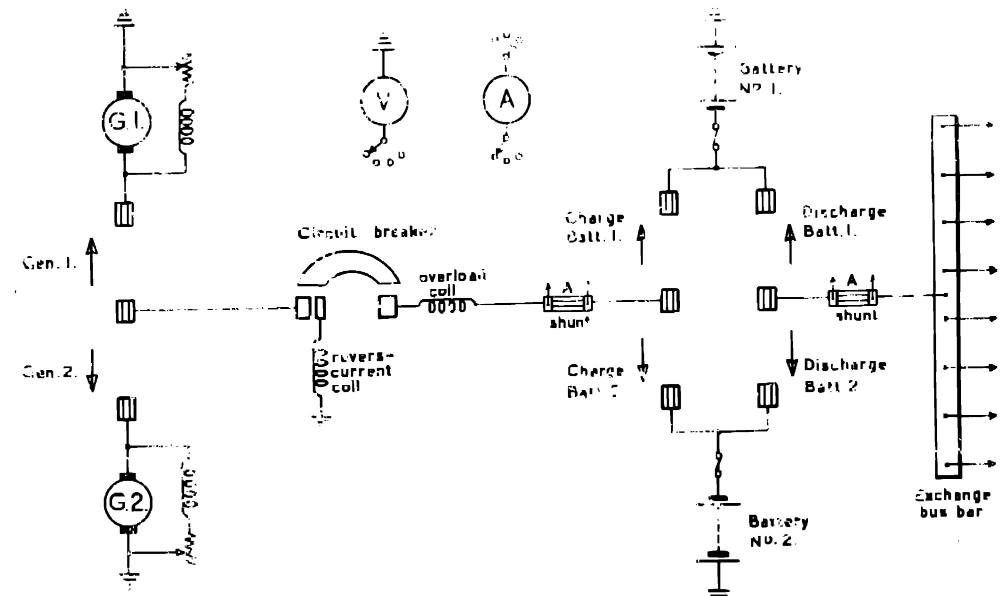


FIG. 615. SCHEMATIC OF CHARGE-DISCHARGE POWER CIRCUIT

The voltage of the generator may then be adjusted to a few volts in excess of the battery voltage before the charging circuit is completed and a reverse current will not then flow and release the breaker. Two generators are provided so that, in the event of one of them requiring maintenance attention, the other may supply the exchange needs. At some manual exchanges only one motor-generator has been installed and, in order to provide for machine breakdowns, the battery is larger than normal and a spare armature is provided for the generator. A knife switch selects either generator and connects it through a reverse current and overload circuit breaker to the charge switch which determines which battery is being charged. The discharge circuit is connected to either battery by means of a make-before-break switch as previously described. Sometimes provision is made for the spare generator to be used to assist the discharging battery during peak load periods. This is known as "floating." The output from the generator must not exceed the exchange load or the excess current will charge the battery, causing its voltage to rise. In this case one circuit breaker per generator is necessary and a choke coil must be used to smooth out the voltage ripples.

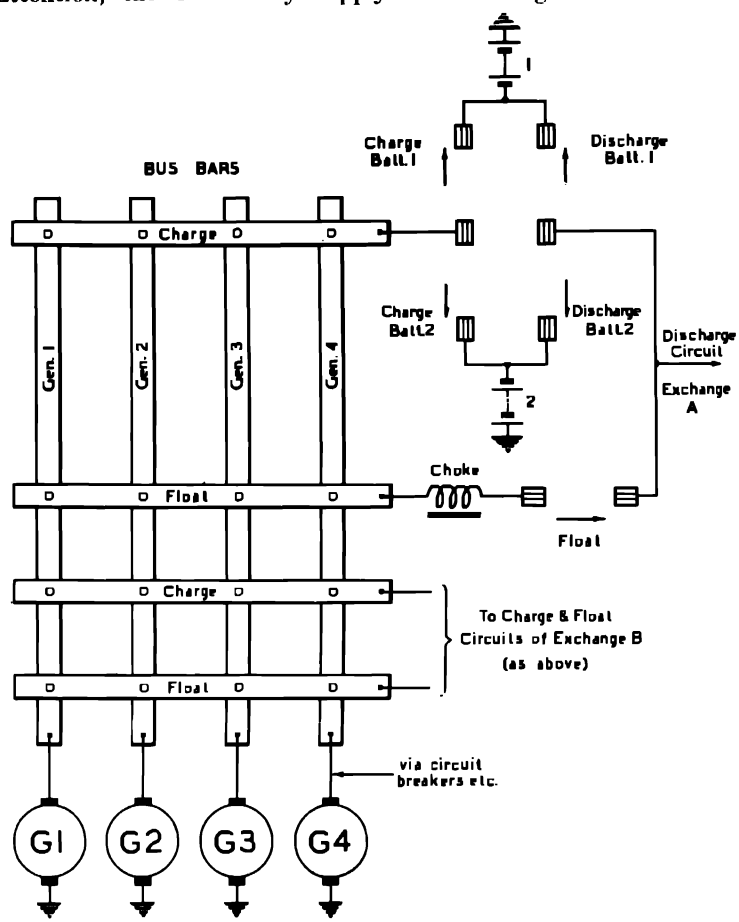


Fig. 616. Charge-discharge Circuit with Floating Facilities (to serve two exchanges in same building)

A simplified circuit with floating facilities is illustrated in Fig. 616. This figure shows the arrangements at a building housing two large exchanges. Four generators are provided and each is connected via its own circuit breaker and ammeter shunt to a copper bar mounted vertically on the power board. The four bars are arranged adjacent to each other and four horizontal bars are mounted behind them in such a way that any of the vertical bars can be put into electrical contact with any of the horizontal bars by inserting a screwed copper plug (Fig. 617) at one of the intersections. The upper horizontal bar is connected to the charge switch for the first exchange and the second bar is connected to a choke coil and thence via a float switch to the exchange discharge circuit. The two lower bars are similarly connected for the second exchange but the connexions have been omitted on the diagram.

Ampere-hour Meters. Ampere-hour meters are, as the name implies, designed to measure the total quantity of electricity (in ampere-hours) which passes through a circuit. The ampere-hour meter is a common component in a number of exchange power plants, especially those of the automatic and semi-automatic type. Fig. 618 shows the principle of operation of a common type ampere-hour meter, whilst Figs. 619 and 620 show the internal arrangements and general outward appearance respectively. The movement consists fundamentally of a copper disc mounted on a spindle which is geared to the indicating hand of the meter. The copper disc is capable of rotation in a bath of mercury, and the circuit is so arranged that a proportion of the total current flows through the disc in a radial direction. A large permanent magnet (the *driving magnet*) embraces the portion

of the disc through which the current passes, and the resultant magnetic field gives rise to a turning moment which is directly proportional to the value of the current through the disc. A second permanent magnet (the *braking magnet*) is located on the opposite side of the disc, and as the disc rotates, eddy currents are induced in the copper. The magnetic field of the eddy currents reacts with

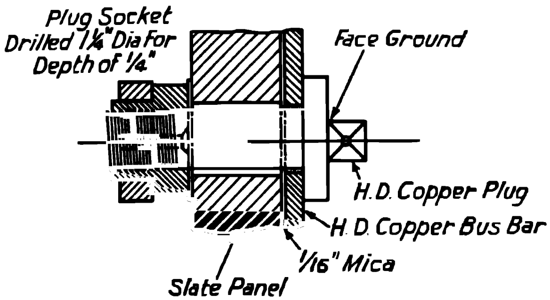


FIG. 617. POWER BOARD CONNEXION PLUG

that of the permanent magnet to provide a counter torque which depends upon the speed of rotation of the copper disc. The arrangements are such that the number of revolutions of the disc is determined by the value of the current and its duration.

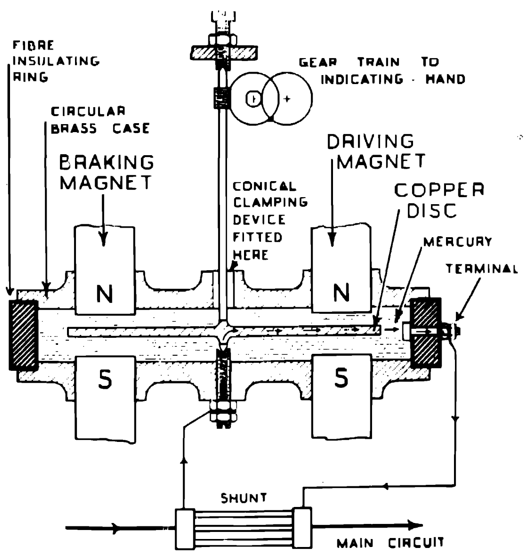


FIG. 618. PRINCIPLE OF AMPERE-HOUR METER

The main mechanism of the ampere-hour meter is substantially the same for all instruments, but the range of the meter can be adjusted to any desired value by the provision of a suitable internal shunt. Ampere-hour meters can be obtained with contacts which will operate at certain predetermined readings. The most sensitive type of meter available, requires a current numerically equal

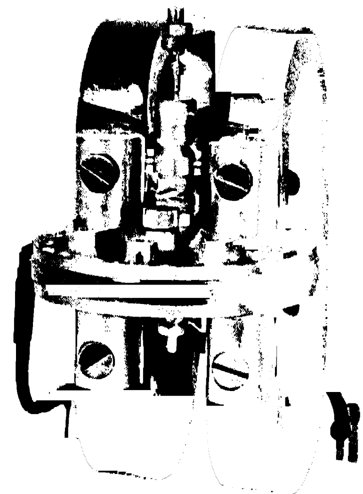


FIG. 619. MAGNET AND MOTOR ASSEMBLY OF AMPERE-HOUR METER

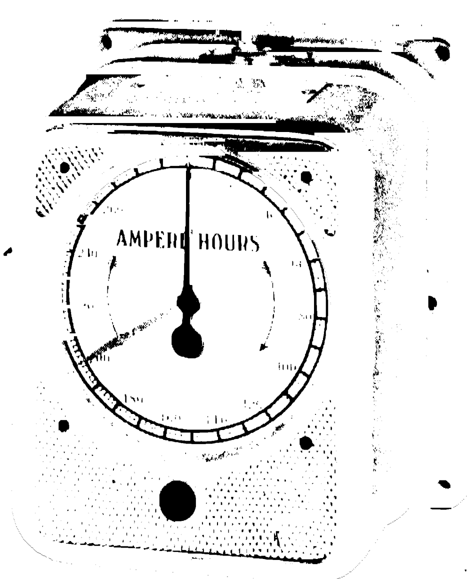


FIG. 620. EXTERNAL APPEARANCE OF AMPERE-HOUR METER

to 0·005 of the ampere-hour range of the meter (i.e. a meter with a total range of 15 Ah requires a minimum current of 0·08 A for its operation).

The ampere-hour meter (Fig. 620) is provided with a means of setting the indicating hand at any desired value, and a second (red) hand, (which is dissociated from the mechanism) can be used as an indicator. Means are provided for the clamping of the moving system and for the sealing of the mercury bath whilst the instrument is being transported.

Ampere-hour Meter Control of Charge. At unattended exchanges it is a common practice to install an ampere-hour meter to give an automatic cut off at the end of the charging period. The ampere-hour meter is provided with a pair of contacts which close when the meter registers zero and the meter is so connected that its readings diminish as the charge proceeds. At the commencement of the charge, the maintenance officer determines from hydrometer readings, the number of ampere-hours it is necessary to put into the battery and sets the meter to this reading. At the completion of the charge, the contacts make and trip a circuit breaker. In the case of a motor generator, this circuit breaker disconnects the supply to the motor but, if a petrol engine is used, then the circuit breaker operates a solenoid valve which stops the petrol supply to the engine. In both cases the generator is disconnected from the battery by the operation of the reverse current circuit breaker. An alarm is extended to the parent exchange if the charge should fail before it is completed.

A typical circuit for use with an engine-driven generator is shown in Fig. 621. The tumbler switch is first put in the "start" position to enable the machine to be started and run up to speed. The generator field rheostat (*R*) is then adjusted to give the required voltage, the ampere-hour meter (*Ah*) is set, and the charging circuit is completed by the closure of the circuit breaker (*CB*). Finally, the tumbler switch is thrown to the "running" position.

When the charge is completed, the ampere-hour meter contact (***Ah*1**) completes the circuit for the trip coil (*TR*) of the circuit breaker which disconnects the battery from the generator ***TR*1** completes the circuit of the solenoid (*CO*) of the petrol cut-off valve, which operates to the generator voltage. The generator now comes to rest, thereby de-energizing *CO*, which, however, remains operated mechanically until it is reset by hand. Should the supply fail before the charge is complete, the no-load release feature of the circuit breaker is actuated and relay *B* operates at the closure of contacts **CB1**. ***B*1** now operates *TR*, whilst ***B*2** connects alarm conditions. Relay *B* is mechanically locked in position once it has operated, so that the disconnexion at ***TR*1** shall not release the relay.

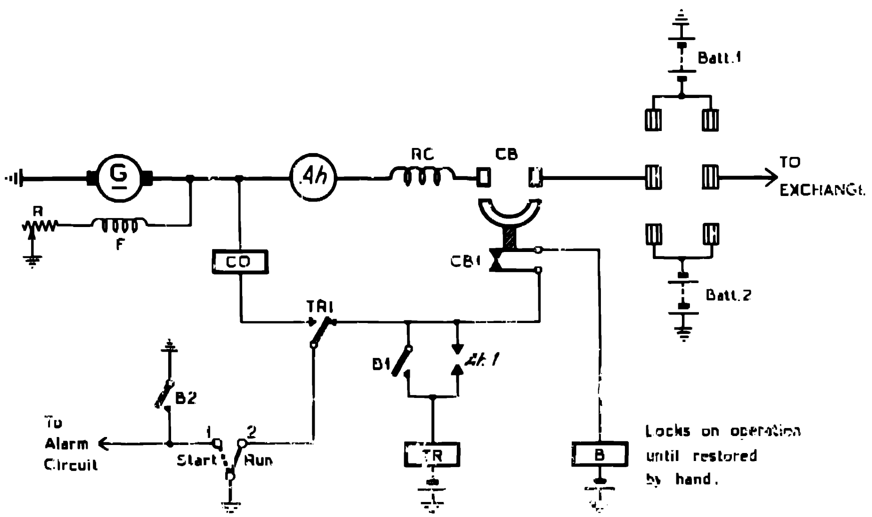


FIG. 621. CHARGE-DISCHARGE CIRCUIT WITH AMPERE-HOUR METER CONTROL OF CHARGE

Automatic and Semi-automatic Power Plant. Automatic and semi-automatic float systems have now largely superseded charge-discharge working for new telephone exchanges. Charge-discharge working is, in fact, now specified only where there is no public electricity supply and in certain cases where the mains are d.c. Existing exchanges are gradually being converted to the more modern methods as opportunity offers. In the new systems, either all or a large portion of the energy required by the exchange is supplied direct by rectifiers or

motor-generator sets, and the battery is used primarily as a reserve of energy to supply the exchange in the event of a mains failure. The advantages of this method if working are:

(*a*) The batteries are kept in a fully charged condition and their full capacity is therefore available if there is a failure of the public electricity supply. Hence, economies can be obtained in the size and initial cost of the batteries.

(*b*) The elimination of regular cycles of charge and discharge considerably prolongs the life of the plates.

(*c*) Maintenance charges are reduced since the battery requires less frequent attention for topping up, straightening of buckled plates, specific gravity readings, etc.

(*d*) The power conversion efficiency is higher, i.e. the losses incurred in storing the energy in the battery and its subsequent reconversion are largely eliminated.

Against the above advantages, automatic float schemes require more or less complex equipment for controlling the voltage at the exchange busbars. Nevertheless, after allowance has been made for the capital cost and maintenance charges of such equipment, there is still a material economic advantage in favour of float working. The detailed design of automatic float schemes is considered in Vol. II, but a general outline of the more common arrangements is given in the following paragraphs.

Divided Battery Float Scheme. The divided battery float scheme is designed for medium and large exchanges where the ultimate daily load exceeds 2000 Ah. With this scheme, the exchange load is served directly from the generators which are provided with automatic voltage regulators to maintain a p.d. of from 50·5 V to 51·75 V at the exchange busbars. A 25-cell battery is floated across the generator output to provide a reserve in the event of a mains failure and to assist in the "smoothing" of the generator output. The voltage across the battery terminals is such that there is no appreciable charge or discharge whilst the battery is being floated. The battery therefore gradually loses its charge due to local action within the cells. A second and similar battery is provided and the batteries are placed on float every alternate week; the loss of charge during the floating period being made up by trickle charging the battery during the idle week. The combined capacity of the two batteries is calculated to provide a 24-hour supply in the event of a mains failure or other emergency.

The current demands of an exchange during the busy part of the day are many times greater than the night load. Hence, during the night it is uneconomical to run the large machine which is necessary to supply the peak day load. In practice, two or three generator sets of graduated size are installed, and by running these generators either singly or in parallel, the most economical arrangement can be adopted to meet any conditions of load. If one machine is, for any reason, out of commission and the remaining machines cannot maintain the full float scheme, it is possible to resort to charge-discharge working, using the available machines.

Facilities are also available for connecting both batteries in parallel to serve the exchange during a mains failure. If such a failure causes an appreciable discharge of the batteries, they must, when the mains are restored, be withdrawn from service in turn and given a full charge at ordinary rates.

Parallel Battery Float Scheme. The parallel battery scheme is fully automatic and of particular application to exchanges where the ultimate daily load is between 100 and 2000 Ah per day. Two identical batteries each of 25-cells are permanently connected in parallel to serve the exchange. An ampere-hour meter is inserted in the battery circuit and is operated by either charge or discharge currents. Local contacts are fitted on the ampere-hour meter so that charging is commenced when the batteries have discharged about 4 per cent of their capacity. When the public supply is a.c., the charging equipment consists of two or more metal rectifier units with a total output sufficient to meet the daily ampere-hour load plus the losses in the batteries. In d.c. areas, two motor-generator sets with automatic starting equipment are provided.

The circuit is such that, once the charging current has been switched on, it continues until the ampere-hour meter reaches zero, i.e. until the battery is fully charged. If, for any reason (e.g. a mains failure) the average discharge current over a period is greater than the charging current, the battery gradually discharges until, at 30 per cent discharge, a contact on the ampere-hour meter completes an alarm circuit. Under normal conditions, the batteries do not discharge much more than 10 per cent, so that there is approximately 90 per cent of the battery capacity available for emergencies. It follows that the battery must have a capacity of about 11 per cent in excess of the daily ampere-hour load of the exchange.

Ampere-hour meters of normal commercial design will not respond to currents of very small magnitude, and such losses are therefore not replaced by the charging circuit. In order to compensate for small losses (and so to avoid the gradual

deterioration of the battery) a small rectifier is arranged to provide a small and continuous trickle charge to the batteries. This method is not applicable to areas served by d.c. mains, and in these circumstances a small constant load is provided which ensures that the minimum discharge current is above the sensitivity limit of the ampere-hour meter.

It has been seen that the terminal p.d. of a battery rises appreciably towards the end of a charge (Fig. 589). The p.d. depends largely on the charging rate and, with a parallel battery float scheme, may reach a value as high as 65 V (2·6 V per cell). The voltage limits of a 50 V automatic exchange are 46 V to 52 V and means must be provided to reduce the voltage to these specified limits. The parallel battery float scheme therefore includes eight counter e.m.f. cells of the type illustrated in Fig. 594, which are cut into the discharge circuit under the control of a contact voltmeter. Normally the cells are all short-circuited by means of contactors but, when the busbar voltage reaches the upper limit (52 V), one contactor is released to insert a pair of the c.e.m.f. cells in the discharge lead. This reduces the voltage applied to the exchange by about 3·8 V (i.e. to 48·2 V approx.). As the battery voltage continues to rise, a second, then a third, and finally a fourth pair of c.e.m.f. cells are switched in. By this means it is possible to keep the p.d. on the exchange within the 52 V limit even although the battery p.d. rises to 67 V. When the charge is shut off, the p.d. of the battery falls quickly and a second contact of the voltmeter (set at 46 V) reapplies the short circuits to the c.e.m.f. cells in progressive stages.

By the provision of two batteries in parallel (instead of a single battery of twice the capacity) it is possible to place one battery temporarily out of service for maintenance work, whilst the exchange is served by the remaining battery. The reserve capacity for contingencies is, of course, halved whilst one battery is out of service.

Single Battery Float Scheme. The single battery float scheme is similar in principle to the parallel battery scheme already described, but is somewhat simpler and is intended for smaller exchanges with an ultimate daily load not exceeding 100 Ah. Four counter e.m.f. cells only are provided and, since the circuit arrangements do not impose on them a prolonged short circuit, it is possible to use a small and cheap type of lead-acid cell. Such cells have an e.m.f. in the order of 2·5 V per cell under load. The cells are switched into circuit in pairs under the control of the contact voltmeter, thereby cutting down the effective exchange voltage in two 5 V stages, i.e. the battery p.d. can rise to 62 V whilst the exchange voltage is kept below 52 V. It is difficult to keep the p.d. of a 25-cell battery below 62 V unless the charging rate towards the end of the charge can be reduced to the 130-hour rate or less. The output of the rectifier must be sufficient to provide the daily load plus battery losses and in practice it is difficult to guarantee that the charging current towards the end of a charge is less than the 130-hour rate unless batteries of excessive capacity are provided. This factor would, in fact, necessitate the provision of batteries with up to six times the capacity required to ensure a 24-hour reserve of energy. The difficulty is overcome by the use of a 24-cell battery which can be charged at the 75-hour rate without the final p.d. exceeding 62 V.

In practice, the capacity of the battery is approximately three times the daily ampere-hour load, whilst the rectifier is of sufficient size to supply the equivalent of the daily load in 20 hours. In the event of a mains failure, substantially the full capacity can be obtained before the voltage drops to the minimum limit of 46 V (1·91 V per cell)—provided that the exchange load is light towards the end of discharge. There is, however, sufficient capacity in the battery to provide service for well over two days before the exchange p.d. falls to 46 V under maximum load conditions.

Assisted Discharge. Some of the advantages of a float system can be obtained on a charge-discharge system, by supplying some of the exchange requirements direct from the mains. Metal rectifier units are available (see Fig. 605) which can be connected across the discharge leads of the power system and do not in any way interfere with the normal change-over arrangements of a charge-discharge installation. The output of the auxiliary rectifier can be so adjusted that it reduces the output from the battery during the busy part of the day and provides a slight charging current during the slack night period. The use of a rectifier may, therefore, materially reduce the number of cycles of charge-discharge and thereby prolong the life of the battery. When a charge-discharge system is provided with an auxiliary rectifier, it is important to ensure that the charging current in the battery at no time causes the p.d. to rise above the maximum permissible limit for the exchange. There is little danger of this occurring if the rectifier output is small compared with the ampere-hour capacity of the battery, and especially if arrangements are made to change-over the batteries at the beginning of the day. If this procedure is followed, the battery is partially discharged by the time that the load falls sufficiently for the rectifier output to be diverted to the battery.

The danger is, of course, greatest if a fully charged battery is switched to the exchange at the end of the busy part of the day.

With the simple assisted discharge scheme described above, no contact voltmeters or other means of voltage control are necessary. If it is desired that the floating rectifier should supply a greater proportion of the exchange load, it may then be necessary to introduce counter e.m.f. cells and voltage control equipment to prevent the p.d. of the exchange rising excessively during periods of light traffic. A simple form of automatic voltage control has been designed for use in conjunction with charge-discharge systems fitted with an auxiliary rectifier. In this scheme, counter e.m.f. cells are provided as in the full float systems. They are switched into and out of the circuit as required by means of a rotary switch, which is controlled via a ratchet and pawl system from the contacts of a voltmeter. If the moving arm of the contact voltmeter makes contact with the high voltage stop, the rotary switch is caused to make one step. If the voltage on the exchange falls to the lower permissible limit, the closure of the lower contacts of the voltmeter moves the rotary switch one step in the reverse direction. The rotary switch can be set by hand to any desired value of voltage.

All Mains Unit for Small Manual Exchanges. Fig. 622 gaves a schematic diagram of an all-mains power supply unit designed primarily for use at small manual exchanges previously served by primary batteries. The unit consists of a full-wave metal rectifier with smoothing equipment to enable the exchange to be worked direct from the power unit. No provision is made for a floating battery but the existing primary cell installation is retained for use in tne event of a mains failure. An alarm relay (A) automatically connects the reserve battery to the exchange and gives an alarm under mains failure conditions. The smoothing circuit is made up of the two series inductances L_1 and L_2 and the large capacity shunt-connected electrolytic condensers.

The unit is capable of serving an exchange where the peak load does not exceed 0·4 A and is therefore suitable for magneto exchanges of up to 50 lines capacity or C.B.S. exchanges of up to 25 lines. The output voltage is approximately 33 V on open circuit and falls to about 20 V at the maximum load (0·4 A). The unit can also be used in conjunction with a small floating secondary cell battery to serve exchanges where the peak current is in excess of 0·4 A but where the daily load is not greater than 4 Ah.

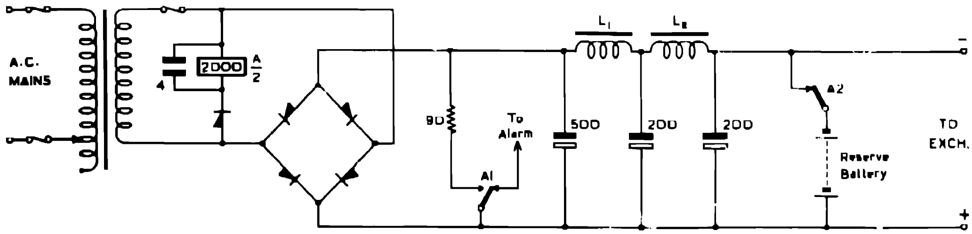


Fig. 622. All-mains Power Unit for Small Manual Exchanges

Power Supply for Subscriber's Apparatus. Electrical energy is required at the subscriber's premises under the following conditions:

(*a*) For the energization of the transmitter at each station in a local battery system.

(*b*) For the energization of the transmitters on Plan Number installations which provide intercommunication facilities between the main and extension instruments (all systems including C.B. and auto).

(*c*) For the energization of the transmitters on extention-to-extension calls and for the operation of the indicators, alarm bells, etc., at all P.M.B.X.'s.

(*d*) For the operation of trembler type extension bells, hooters, etc., as required.

The installation of primary cells at the subscriber's premises is the only practical method of providing power for the energization of the transmitter on simple exchange lines in a local battery system and for Plan Nos. in a C.B. or automatic system. Normally, the battery consists of two Leclanché cells of the WK4 type, but in exceptional circumstances an additional cell, or cells of larger capacity, may be provided to meet transmission or traffic requirements.

Power for P.M.B.X.'s (and House Exchange Systems) may be supplied either over a wire (a power lead) from the exchange or, alternatively, by the provision of a primary or secondary cell battery at the subscriber's premises. The method to be used in any particular circumstances is determined by economic considerations, but first it is necessary to know:

(*a*) the maximum current demand;

(*b*) the minimum voltage at the subscribers premises to ensure satisfactory operation;

(*c*) the daily load (in ampere-hours) of the installation.

It is readily possible to calculate the current drain at any type of P.M.B.X. for the various classes of call. If the volume of traffic is known, then it is possible to estimate the maximum current demand and the daily ampere-hour consumption of energy. Whilst this procedure is applied to the larger P.M.B.X.'s, it is often unnecessary with the smaller installations where an assumed nominal load will suffice for all except abnormal cases. Table IX gives details of the power consumption of the more common P.M.B.X.'s. The current consumption for exchange calls, extension calls, and for the operators transmitter are detailed, together with the minimum working voltage at the P.M.B.X. busbars. A nominal load for average conditions of traffic is also given for the smaller switchboards so that an assessment can be made of the power requirements without a detailed study of the traffic.

Generally speaking, primary cells are suitable only when the maximum current does not exceed about 1·5 A and where the daily load is 1·5 Ah or less. For larger demands the installation must be served either by secondary cells (and a suitable charging plant) at the subscribers premises or by a power lead from the exchange.

A final decision on the most suitable method of supply can only be made from a comparison of the annual charges of the alternative methods. If a power lead is considered, the total cost of supplying energy is made up by:

(*a*) The annual charges of the line itself to cover interest on capital, depreciation, maintenance, etc. This figure depends upon the method of distribution (i.e. overhead or underground) and the number and gauge of conductors used.

(*b*) The annual cost of electrical energy supplied from the exchange. In a large exchange the energy consumed by the P.B.X.'s is small in comparison with the total consumption of the exchange and the cost is small. On the other hand, in a small exchange, the consumption of the P.B.X's may be a material part of the total power load and the cost is consequently somewhat higher.

TABLE IX

POWER CONSUMPTION OF PRIVATE MANUAL BRANCH EXCHANGES

Type		Current per exch. call (A)	Current per extn.-extn. call (A)	Current per operators position (A)	Nominal Average Load: Maximum Current (A)	Nominal Average Load: Ampere-hours per day (Ah)	Minimum voltage at P.B.X. busbars (V)
Cordless switchboards in L.B. areas	1 + 3	0·011	0·007	—	0·038	0·019	14
	2 + 4	0·011	0·007	—	0·038	0·033	14
	3 + 9	0·011	0·007	—	0·055	0·048	14
Cordless switchboards in C.B and auto areas	1 + 3	—	0·054	—	0·054	0·025	12
	2 + 4	—	0·054	—	0·054	0·05	12
	3 + 9	—	0·054	—	0·108	0·09	12
Cord Type switchboards	25 line	0·012	0·058	—	0·21	0·35	12
	65 line	0·024	0·06	0·05	0·43	1·3	12
	180 line	0·024	0·06	0·05	0·5	1·5	12
P.M.B.X. No. 9		0·073	0·076	0·07	0·52 per position	3·8 per position	16
P.M.B.X. No. 1A		0·018	0·310	0·108	—	—	20

The current consumption and daily load determines whether primary batteries or a secondary cell installation is necessary as an alternative to the provision of a power lead. In general, primary batteries can be used for switchboards of up to 65 lines capacity, but on larger installations the load usually necessitates the provision of secondary cells and charging plant.

Power Leads. Before a study can be made of the relative costs of supplying energy by means of a power lead or by the provision of local batteries,

it is necessary to determine the number and gauge of conductors required to meet the circuit conditions. If the voltage of the main exchange is E and the minimum permissible voltage at the P.M.B.X. busbars is e, then a total voltage drop in the power lead of $E - e$ is permissible. If the maximum current demand is I, then the resistance of the line must not exceed:

$$\text{Resistance} = \frac{E - e}{I} \text{ (ohms).}$$

If, for example, the nominal e.m.f. of the exchange battery is 40 V and the minimum p.d. at the P.B.X. is 12 V, then, if the maximum current on the power lead is 0·5 A, the line resistance must not exceed $(40 - 12)/0{\cdot}5 = 56\ \Omega$. Telephone wires are invariably provided as "pairs," and hence there is little object in utilizing one wire of a pair for a power lead. If both wires are bunched, the joint resistance is one-quarter of the loop resistance, i.e. in the above example it would be possible to work the P.B.X. over a power lead which has a loop resistance of 224 Ω. If the resistance of one pair of wires (bunched) is too high, several pairs of wires may be commoned together in order to bring the joint resistance down to the required value.

It is not necessary to provide a separate power lead for each individual P.M.B.X. If a number of such installations are grouped together in one locality they can be served by a single power lead. It should be noted, however, that such a grouping increases the maximum current demand and hence requires a line of lower resistance. In cases where the peak load causes too great a potential drop in the power lead, it is of advantage to provide a battery of portable type secondary cells at the subscribers premises. A standard unit is available which consists of ten 12 Ah cells in a suitable box. The cells are "trickle charged" over a power lead from the exchange.

At the exchange, a number of power leads are usually bunched together so that they can be served by a 1 A fuse. This fuse is of the alarm type (*q.v.*), and it is important to ensure that, if an earth fault occurs on the line, the alarm type power fuse will blow before the line fuses on the M.D.F. If the M.D.F. fuses blow but the power fuse does not, no alarm will be given and the power supply to a number of P.M.B.X.'s may be interrupted without any indication being given.

At 22 or 24 V exchanges, the power leads can be connected to the full exchange voltage. In C.B. exchanges where there is an 8 V meter battery, it is often advantageous to serve the higher resistance power leads from a 30 V supply made up of the main exchange battery and the meter battery in series. At 40 and 50 V exchanges, the normal exchange voltage is often too high for serving the shorter power leads in the area. In these cases it is usual to provide a counter e.m.f. battery which reduces the voltage applied to the power line to 30 – 36 V. Even in 50 V exchanges, however, it is advantageous to have the full exchange voltage available for the higher resistance power leads, and in practice it is usual to have available two voltages for the supply of power to P.B.X. subscribers.

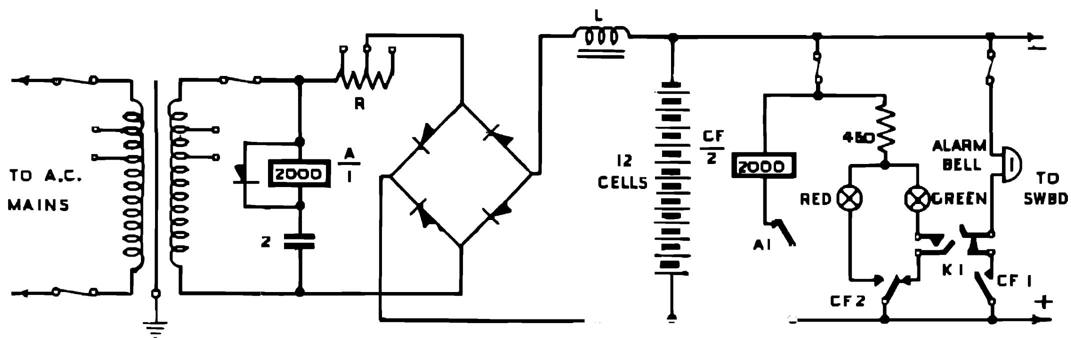


FIG. 623. FLOAT POWER SCHEME FOR PRIVATE MANUAL BRANCH EXCHANGES

Automatic Float Scheme for P.M.B.X.'s. Primary cells or power leads are unsuitable for large private manual branch exchanges owing to the heavy power consumption. Until a few years ago it was usual to install, for such cases, a secondary cell installation with charge-discharge working. An automatic single battery float scheme has now been designed for use when an a.c. power supply is available at the subscriber's premises. This scheme not only materially reduces the capital cost of the installation but also avoids the frequent maintenance visits required for the "changing-over" of the batteries on a charge-discharge plant.

The circuit arrangements of the float scheme are given in Fig. 623. The power unit consists of a mains transformer coupled to a bridge connected metal rectifier with a suitable smoothing choke (*L*) in the d.c. output. Tappings on the transformer secondary winding together with a tapped resistance (*R*) enable the output to be adjusted over a small margin. The rectifier is connected direct to a 12-cell battery and to the switchboard busbars. An a.c. relay (*A*) is wired to the secondary of the mains transformer and is normally operated. If a mains failure occurs, *A* releases and at *A*1

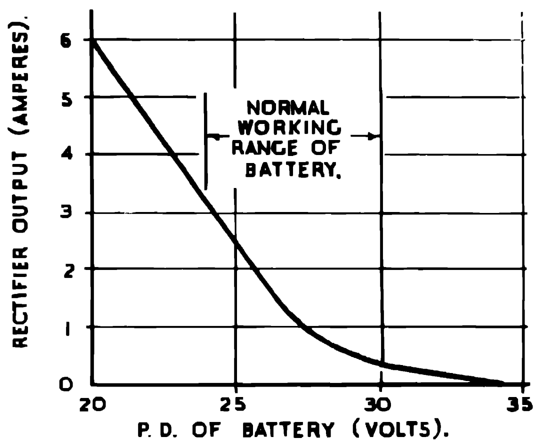


FIG. 624. RECTIFIER OUTPUT CHARACTERISTIC

operates relay *CF*. The first contact of *CF* (*CF*1) closes the circuit of an alarm bell whilst *CF*2 causes a red alarm lamp to glow. The operation of key *K*1 silences the alarm bell and prepares a circuit for the lighting of a green lamp when the mains voltage is restored. When the green lamp glows, the restoration of *K*1 returns the circuit to normal. The lamps and key are usually mounted in a small case on the top of the switchboard where they can readily be seen by the operator.

No strict voltage control is provided but the equipment is designed to maintain a voltage of between 24 V and 30 V at the busbars. Advantage is taken of the wide voltage margins permissible at a P.M.B.X. to provide a very simple and automatic control of charging. A fully-charged 12-cell battery has a terminal voltage of approximately 30 V when on charge at a fairly low rate. When the battery commences to discharge, the voltage quickly drops to 24–25 V. The rectifier circuit is designed so that the output current falls steadily as the battery voltage increases above 24 V until the voltage on the busbars approaches 30 V. The curve (Fig. 624) now flattens out and stabilizes at a small trickle charge value. If, with the rectifier of Fig. 624, the battery is discharging due to a heavy load, the terminal voltage is about 24 V. The rectifier gives an output of 3 A

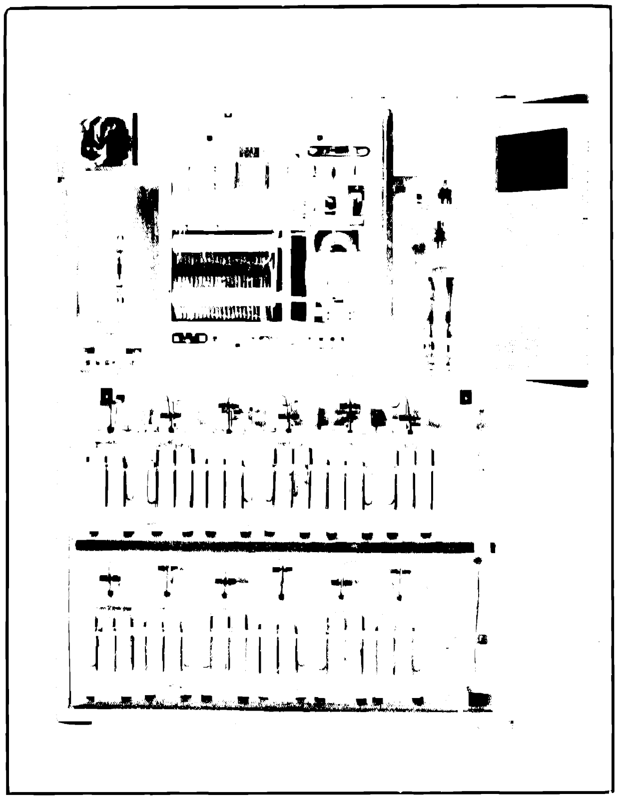


FIG. 625. GENERAL VIEW OF COMPLETE FLOAT POWER PLANT
(*P.O.E.E.J.*)

under these conditions which gives the maximum assistance to the discharge. As the load decreases the rectifier supplies more and more of the load and finally commences to charge the battery. The charging continues at a gradually decreasing rate and is cut down to a trickle charge of some 0·3 A as the voltage rises sharply when the battery is fully charged. Thus the battery is always fully charged after each daily cycle of load, provided that the rectifier is sufficiently large to give an ampere-hour output (at 24 V) greater than the daily ampere-hour consumption.

Three rectifier units for P.M.B.X. work have been standardized by the Post Office, viz.:

Rectifier No.	Current at 24 V (A)	Suitable Battery Capacity (Ah)	Max P.M.B.X. Load (Ah/day)
38A	1·5	20	15
38B	3	50	30
38C	6	75	60

For larger loads rectifiers may be connected in parallel. Fig. 625 shows a compact cabinet designed to accommodate the complete power plant for a P.M.B.X.

Ringing Machines. Alternating current at a frequency in the order of 16⅔ c/s is required at every telephone exchange for the ringing of subscribers' bells. At very small manual exchanges the ringing current is produced by means of a hand generator on each operator's position, but in all exchanges of more than, say, two positions, it is usual to provide power ringing equipment.

The normal method of supplying ringing current is by means of a ringing machine. Where public electricity mains are available, the normal ringing machine (or *ringer*) is driven direct from the mains. A reserve battery-driven ringer is often provided and in some cases the circuits are arranged to provide an automatic changeover from one machine to the other in the event of failure of the regular ringing supply.

Mains driven ringers consist of a suitable motor (a.c. or d.c.) directly coupled to a low frequency alternator of the required output. For large exchanges the machine may be capable of as much as 300 W output or more, but smaller machines with outputs as low as 15 W are available for use at exchanges where the demand is not so great. Battery driven ringers are usually if the dynamotor type, i.e. the motor and generator windings are placed on the same armature. The alternating ringing current is collected by means of carbon brushes in contact with slip rings.

Continuous ringing current is required for the ordinary A-position cord circuits of a manual exchange, but when automatic ringing is employed (e.g. on keyless order-wire junctions) interrupted ringing current is used. The standard periodicity of interrupted ringing current in this country is 0·4 sec. on, 0·2 sec. off, 0·4 sec. on, 2 sec. off. The interruptions are provided by means of slow speed cams on the ringing machine. In order to reduce the maximum peak demand on the machine, it is normal practice to provide three sets of interrupted ringing so timed that, at any instant, ringing is only being delivered to one of the phases. This is obtained by placing the slow speed cams on the ringing machine at 120° intervals.

In addition to the interrupted ringing current, most modern exchanges require a variety of tones. The four standard tones are:

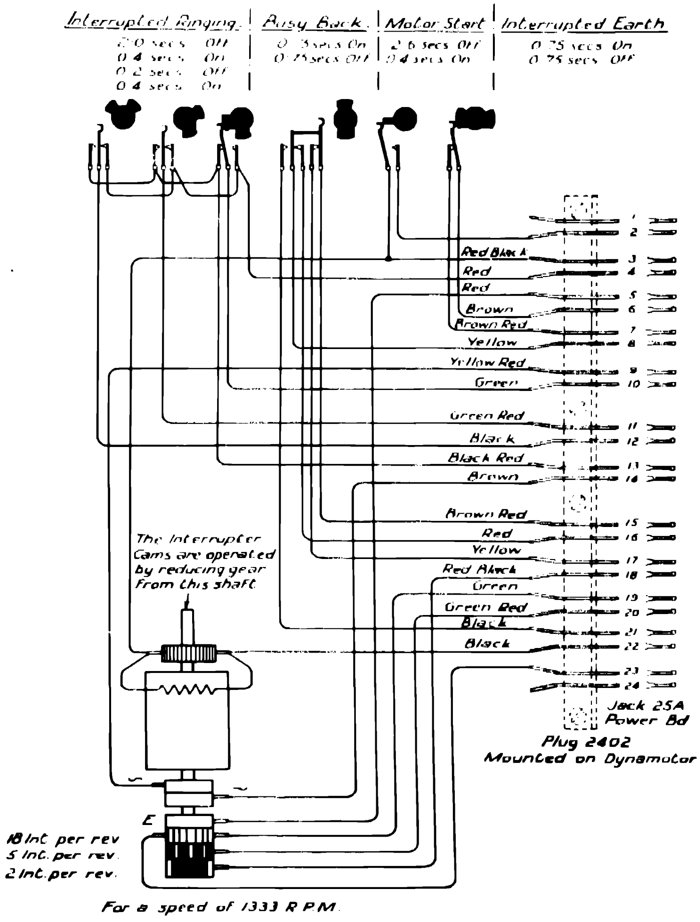


FIG. 626. WIRING OF SMALL TYPE RINGING DYNAMOTOR

(*a*) *Busy Tone.* A tone of 400 c/s connected for 0·75 sec, and disconnected for 0·75 sec.

(*b*) *Number Unobtainable* (*or out of order*) *Tone.* A continuous tone of 400 c/s.

(*c*) *Ringing Tone.* A tone of 133 c/s interrupted at the same frequency as the ringing current.

(*d*) *Dialling Tone.* A continuous tone of 33 c/s. This tone is required only at automatic exchanges.

Until recently the alternating current required for the various tones was produced by means of a series of commutators mounted on the ringing machine shaft. These commutators interrupted a direct current through the primary of a transformer, thereby inducing alternating voltages in the secondary winding. The slow speed interruption of the tones is, as in the case of the ringing current, produced by slow speed cams on the machine. Fig. 626 shows a wiring diagram of a small ringing machine of the dynamotor type. This particular machine is designed to run at a speed of 1333 r.p.m., and provides 3 tone drums arranged to give 18, 5, and 2 interruptions per revolution. The three slow speed cams for interrupted ringing are shown, whilst two further cams provide the interruptions for Busy Tone and an interrupted earth supply at the same speed for flashing purposes.

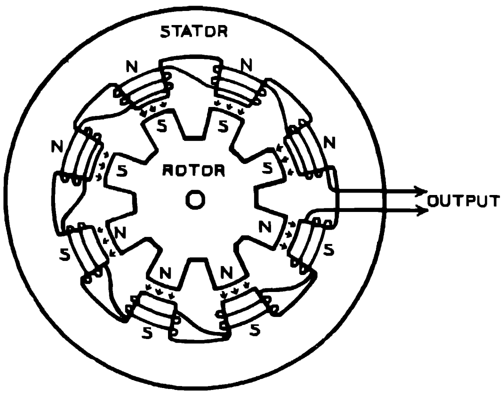


FIG. 627. MAGNETIC CIRCUIT OF INDUCTOR TONE GENERATOR

Ringer Start. In small exchanges it is uneconomical to allow the ringing machine to run continuously. In such circumstances ringer start contacts are provided on the cord circuit ringing keys. The operation of a ringing key energizes a high resistance "motor-start" relay and the contacts of the latter complete the ringing machine motor. To guard against "flick operation," it is usual to fit a cam on the ringing machine which is so arranged that, once the motor is started, it will continue to run for a period of three seconds—irrespective of the position of the ringing start keys (see Fig. 626).

Ringing Machine with Inductor Tone Generator. The commutator method of producing tones as described above is now obsolescent. In all modern ringing machines, the tone is produced electromagnetically in the machine itself. Fig. 627 shows the principle of the tone inductor. The stator of the machine consists of a number of pole-pieces built up of thin iron laminations, whilst the rotor is in the form of a toothed wheel also constructed

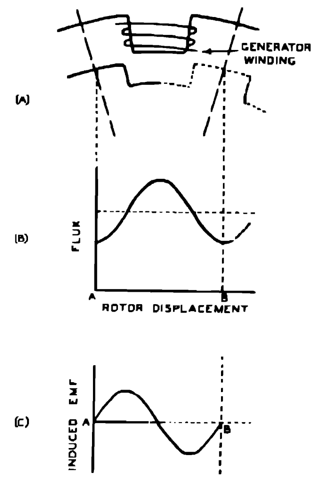


FIG. 628. SHOWING HOW E.M.F. IS PRODUCED BY MOVEMENT OF ROTOR TEETH

of laminated iron. The stator is magnetized by d.c. through a field winding (not shown in Fig. 627). Fig. 628 shows a section of the rotor and one of the stator pole-pieces. A magnetic flux is produced across the air gap between the stator and rotor, due to the direct current on the stator winding. The value of this flux depends upon the magnetomotive force of this winding and also upon the reluctance of the magnetic circuit at any particular instant. As the rotor moves, the value of the flux also changes due to the varying length of the air gap as the teeth of the rotor pass the pole-pieces. A second winding is provided on each pole-piece of the stator. As the flux changes due to the rotation, the change of flux produces an induced e.m.f. in the windings of the stator pole-pieces. It is clear that the flux has its greatest value when the rotor tooth is directly opposite the pole-piece, and the flux is a minimum when the slot between the two rotor teeth is opposite the pole-piece. The greatest *change* of flux occurs at a point midway between these two. With 8 poles

(as shown in Fig. 627) 8 complete cycles of alternating current will be generated for one revolution of the rotor. Thus, if the speed of the generator is 1000 r.p.m., an alternating current of $133\frac{1}{3}$ c/s will be generated. In the actual machine, the rotor consists of 4 sets of stamped soft iron discs in order to generate the required frequencies. Two sets contain 24 teeth, one 8 teeth and the last 2 teeth (to produce 400, $133\frac{1}{3}$, and $33\frac{1}{3}$ c/s respectively). The generator windings of the stator pole-pieces are connected in series (one half of the pole-pieces being reversed) so that the total

REGULAR MACHINE, RINGING AND TONE CIRCUIT

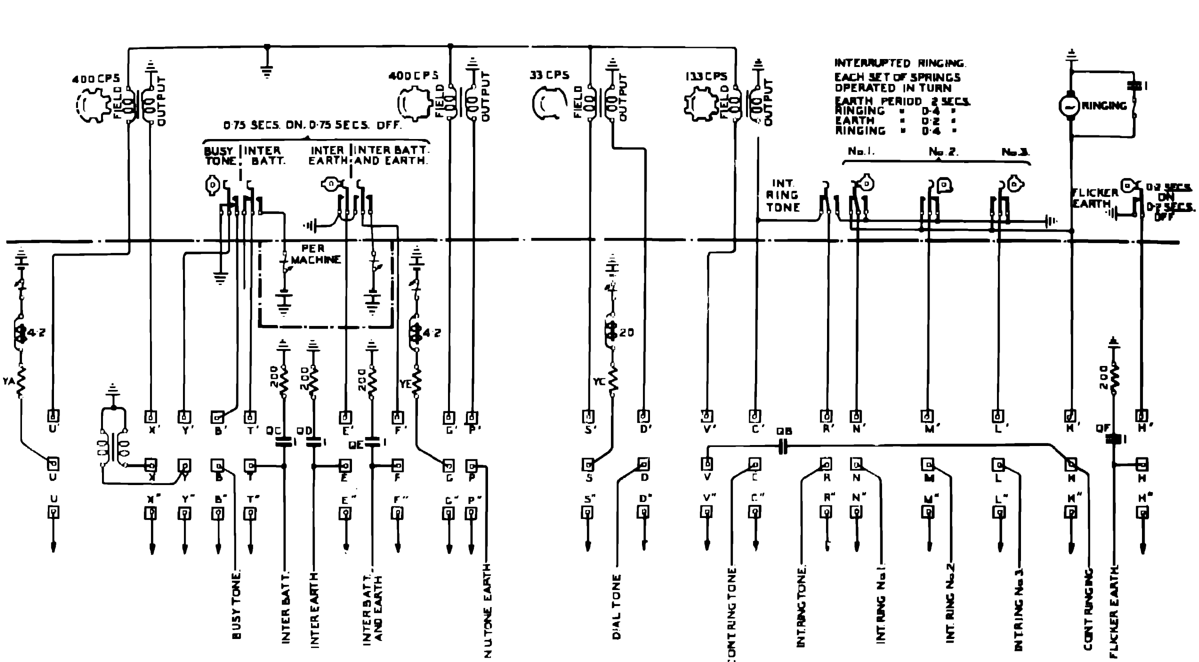


FIG. 629. CIRCUIT OF RINGING MACHINE WITH INDUCTOR TONE GENERATOR

e.m.f. generated is the sum of the e.m.f.'s generated in each coil.

Fig. 629 shows the connexions of a ringing machine of the tone inductor type. The switches in the lower part of the illustration are required for the automatic changeover to the reserve ringer. It should be noted that a choke is included in the battery supply to the field energizing windings of the tone generator. This inductance is required to minimize the eddy currents in the field coil due to the changes of flux and thereby to prevent the absorption of energy by the field winding.

Fig. 630 shows a mains driven ringing machine of the tone inductor type. The slow speed interrupters will be seen on the extreme left. Fig. 631 shows a battery operated machine of the same type.

Static Ringing Converter. The obvious maintenance advantages of a static device for the provision of ringing current, have led to the introduction of a unit for producing ringing current at a frequency of $16\frac{2}{3}$ c/s from the 50 c/s mains supply. Two models have been standardized, the first giving an output of up to 5 W and the second with an output of up to 15 W. The smaller converter is sufficient to supply power for the ringing of from 15 to 20 magneto bells simultaneously, and one of these units is adequate for a manual exchange of up to 15 positions. Models are available either for rack mounting in telephone exchanges or for wall mounting in subscriber's premises. The units are very compact (the 5 W model is some 10 in. × 9 in. × 6 in.) and require a very small amount of maintenance attention.

The circuit arrangements of the 5 W converter are given in Fig. 632. The equipment consists essentially of an auto-transformer (XA), a circuit tuned to the 3rd sub-harmonic, ($16\frac{2}{3}$ c/s) of the standard mains frequency (50 c/s), and devices for starting and maintaining the oscillations in the tuned circuit. Condenser QA and the primary of the output transformer XB form the $16\frac{2}{3}$ c/s

tuned circuit. When the mains are switched on, a rectified charge is given to condenser *QA* through the rectifier *ZB*. When the voltage across the condenser reaches a sufficiently high value, relay *RA* operates. This relay is made slow to operate

Subsequent to switching, the $16\frac{2}{3}$ c/s oscillations in the tuned circuit are maintained by periodical pulses of current through choke *LA*. The principle of the circuit operation is shown diagrammatically in Fig. 633. E_1 represents the 50 c/s

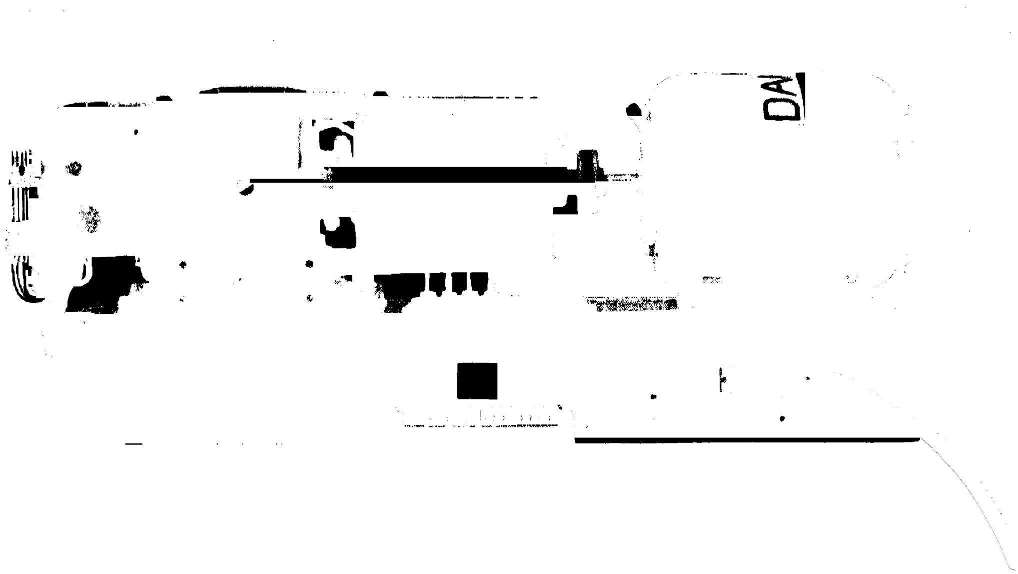


FIG. 630. MAINS DRIVEN RINGING MACHINE WITH INDUCTOR TONE GENERATOR

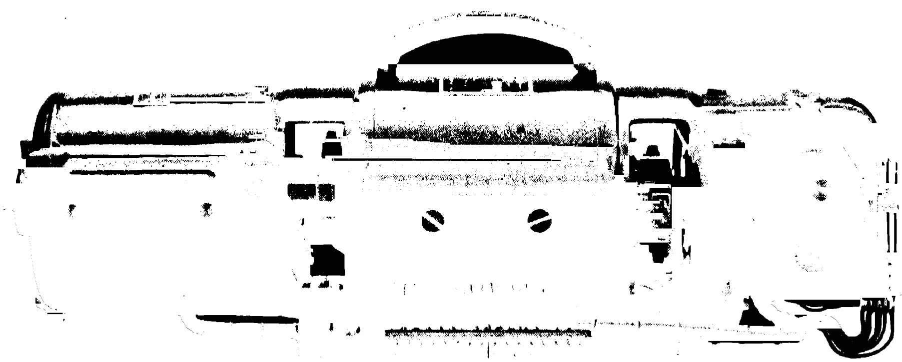


FIG. 631. BATTERY DRIVEN RINGING DYNAMOTOR WITH TONE INDICATOR

in order that *QA* can attain a sufficiently large p.d. before it is switched to the oscillatory circuit by contact ***RA*1**. After switching, relay *RA* holds due to the voltage across the oscillatory circuit, which is rectified by the bridge network *ZA*.

voltage wave of the mains supply. Half-wave voltages (E_2) are applied to condenser *QA* via rectifier *ZB*. When the voltage E_2 reaches the operate value of *RA*, the charging circuit is disconnected and condenser *QA* with its charge is

applied to the inductive component of the tuned circuit (XB). Oscillatory currents now circulate round this tuned circuit at the resonant frequency

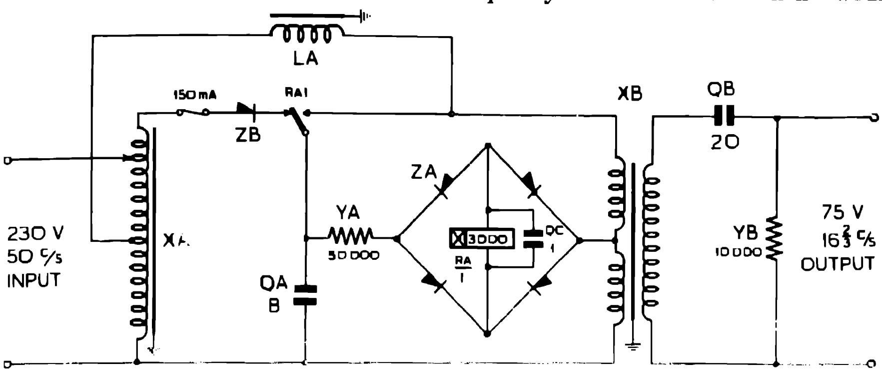
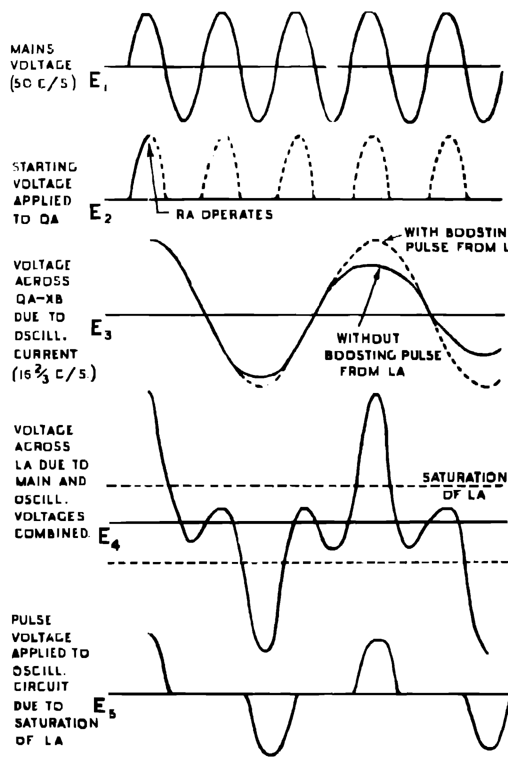


FIG. 632. STATIC MAINS OPERATED FREQUENCY CONVERTER

of the circuit (i.e. $16\frac{2}{3}$ c/s). If no additional energy is supplied to the tuned circuit, these oscillations will gradually die down due to the losses in the circuit. The voltage across the tuned circuit due to the oscillatory currents is shown by curve E_3. Now the voltage across impedance LA is the vector sum of E_1 and E_3. The complex wave resulting from these two voltages in series is shown in Fig. 633 as E_4. If E_1 and E_3 are in the proper phase relationship, then it is clear that a peak voltage is applied to LA every 3rd half cycle of the mains voltage. LA is so designed that it offers a high impedance when there is a small p.d. across it, but the core of the choke saturates with the peak voltages. This saturation occurs at every 3rd half cycle, and the mometary reduction of impedance of LA due to the saturation gives a pulse voltage (E_5) to the oscillatory circuit. The injection of this pulse every 3rd half cycle of the mains frequency makes good the losses in the oscillatory circuit and so maintains the amplitude of the $16\frac{2}{3}$ c/s oscillatory currents.

It is clear that the circuit will function satisfactorily only if voltages E_1 and E_3 have the proper phase relationship. If the phase of the voltage across the oscillatory circuit (E_3) is incorrect, then the high voltage peaks every 3rd half cycle (E_4) will not be obtained and the oscillatory currents in the tuned circuit will die down. Relay RA releases under these conditions, but on the restoration of $RA1$, the relay reoperates to the rectified mains frequency. Thus relay RA continues to operate and release until the correct phase relationship is obtained. In practice correct phasing is obtained after one or two operations of RA, and the relay then holds continuously until the mains are disconnected from the converter.

Condenser QB in the output circuit is provided to prevent an excessive load on the output transformer XB which would otherwise tend to stop the oscillations. Resistor YB provides a protective leak path in order to avoid excessive output voltages under light load conditions. It should be noted that during operation very high voltages are produced across various parts of the circuit, and the unit is consequently fitted with protective



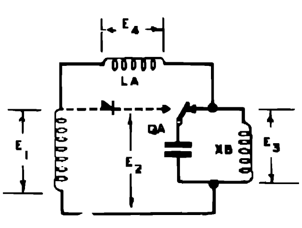


FIG. 633
DIAGRAMMATIC REPRESENTATION OF OPERATION OF RINGING CONVERTER

devices which prevent the removal of the cover until the mains are disconnected.

Ringing Vibrator. The vibrator is a useful means of providing ringing current at small exchanges where the absence of power and of large capacity batteries prohibits the use of ringing machines. The ringing vibrator (Fig. 634) is essentially a trembler bell mechanism with its armature loaded

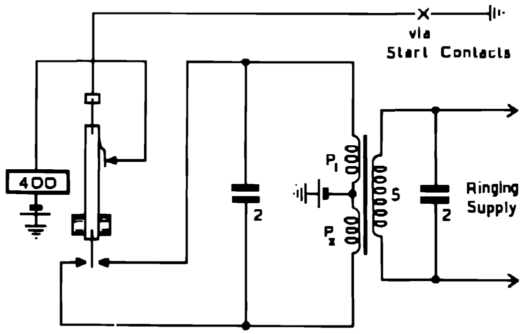


FIG. 634. RINGING VIBRATOR

to give a vibration frequency in the order of 20 periods per second. Auxiliary contacts on the armature apply earth alternately to the two windings (P_1 and P_2) of a transformer and the connexions are such that the flux in the transformer core is reversed at each swing of the armature. The flux reversals in the core of the transformer induce an alternating e.m.f. in the secondary winding (S) which is connected to the ringing supply leads of the exchange. The 2 μF condensers across the primary and secondary windings shunt away the higher frequency components so that the alternating e.m.f. is more or less sinusoidal.

Ringing Supply for Subscribers' Installations. At the smaller P.M.B.X.'s the operator calls the extension by means of a hand generator fitted to the switchboard position. This method of calling becomes somewhat cumbersome at the larger P.M.B.X.'s, and at such installations it is desirable to provide power ringing in the interests of operating efficiency. P.M.B.X. installations are in general not of sufficient size to justify the provision of a ringing machine, and in practice power ringing is provided by one or other of the following methods:

(*a*) By a ringing lead from the exchange.

(*b*) From the a.c. mains by the use of static frequency convertors.

(*c*) By utilizing 50 c/s current obtained from the a.c. mains via a step-down transformer.

(*d*) By the use of battery operated ringing vibrators.

The method to be used in any particular case depends on the amount of energy required, the availability and annual charges of wires to the exchange, the type of public electricity mains, etc.

A ringing lead consists of a pair of wires from the exchange terminated on the ringing commons of the P.M.B.X. switchboard. In order to safeguard against a short circuit on the main exchange ringing supply, it is usual to feed such ringing leads through an 0·5 A fuse and a lamp which has a nominal resistance of 660 Ω. It is important that the ringing supply should be a loop circuit in order to prevent ringing induction on nearby speech conductors.

The static frequency convertors sometimes used on the larger P.M.B.X.'s are exactly the same as the converters used in small public manual exchanges and have already been described. A very economical method of supplying ringing current is by the use of a step-down transformer from the a.c. mains. The alternating current available for the ringing of the bells is, of course, 50 c/s, and is, therefore, of much higher frequency than the normal ringing supply. It has been found, however, that under the normal conditions at a P.M.B.X., the standard magneto bell will respond satisfactorily to such currents.

Voice Frequency Generators. Alternating currents of voice frequency are required for the 4-frequency and 2-frequency V.F. signalling systems described in Chapter XIII. The standard voice-frequency generator is of the inductor type and provides sinusoidal voltages at the four standard frequencies, i.e. 500, 600, 750, and 900 c/s. The general arrangements of the machine are shown diagrammatically in Fig. 635. There are 4 laminated rotor wheels (one for each frequency) with teeth specially cut to give a pure sinusoidal waveform. The stators have corresponding teeth and are wound with coils connected to the output circuit. Polarizing coils are provided between each pair of rotor wheels and are excited by means of a direct current supply. When the machine is at rest, the flux in the air gaps and in the stator pole-pieces is constant, but when the rotors are made to revolve at constant speed, the variation in the reluctance of the circuit, caused by the passage of the rotor teeth across the stator pole-pieces, produces an alternating e.m.f. in the stator coils of substantially sinusoidal waveform.

Where the mains are a.c. and are frequency controlled, the motor is of the synchronous type, but in all other cases the machine is driven by a d.c. motor which is energized from the exchange

battery or from the mains via a rectifier. The reserve machine is always driven from the exchange battery and the circuit is such that the reserve

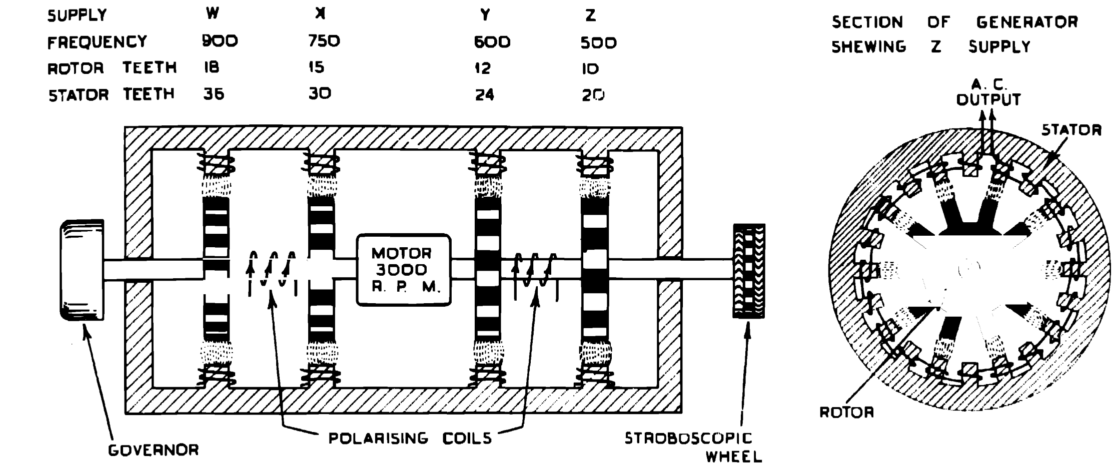


FIG. 635. PRINCIPLE OF 4-FREQUENCY V.F. GENERATOR

machine is automatically started in the event of any failure of the regular machine.

It is of the utmost importance that the output frequency shall be as constant as possible. The

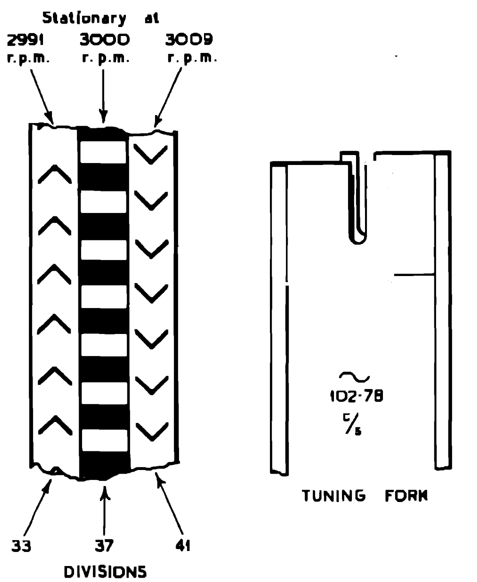


FIG. 636. METHOD OF TESTING V.F. GENERATOR SPEED

speed of the d.c. machine is regulated by a centrifugal governor which maintains the speed at 3000 r.p.m. ± 0·3 per cent. A stroboscopic wheel is provided at the end of the generator shaft so that the speed can be checked by the use of a specially designed tuning fork (Fig. 636).

The motor itself is provided with three field windings (Fig. 637). The first winding (A) is served direct from the d.c. supply. The second winding (C) is in opposition to the first winding and is served from the d.c. supply via a ballast resistor. The use of two windings in this manner minimizes the change of speed for a given change of terminal voltage. Rheostats R_A and R_C are provided to obtain a critical balance between the

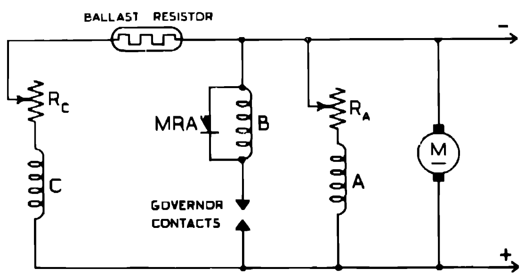


FIG. 637. MOTOR CIRCUIT OF V.F. GENERATOR

main and opposing fields. A third winding (B) is in series with the governor contacts and gives the final regulation of speed to within limits of ± 0·3 per cent. The metal rectifier (MRA) is placed across field winding B in order to prevent high induced voltages when the governor contacts open.

The motor of the a.c. type of machine is of special design and behaves as an induction motor whilst it is being run up to full speed, and then runs at synchronous speed (i.e. 3000 r.p.m.) under the control of the mains voltage. In the a.c. machine the d.c. polarizing coils are energized via a small

copper-oxide rectifier and a ballast resistor lamp from the a.c. mains. The voice-frequency output of both types of machine is approximately 200 mA at 20 ± 1 V.

EXERCISES XX

1. Explain how the internal resistance of a Leclanché cell may be ascertained by the use of a voltmeter and a resistance coil of known value. State the precautions that are necessary in order to obtain a reliable result. Why is it usual, in making the calculation, to neglect the effect of voltmeter resistance? (*C. & G. Telephony, Grade I.* 1944.)

2. Explain the principle of a simple secondary cell and show why a device of this type cannot be charged directly from an alternating current supply. (*C. & G. Tech. Elec., Grade I.* 1943.)

3. Explain the term "specific gravity." State the reasons for measuring the specific gravity of the electrolyte in a secondary cell, and describe with the aid of a sketch, the instrument employed for the purpose. Give typical values of the specific gravity that might be obtained from a cell (*a*) when fully charged, (*b*) after a normal discharge. (*C. & G. Telephony, Grade I*, 1942.)

4. A fully-charged exchange battery at 10 a.m. is put on load at an average of 6 A until 8 p.m., after which the average load is reduced to 1 A. At 8 a.m. next morning the battery is deemed to be discharged and is taken off load. It is then brought back to its fully-charged condition by immediate recharging at 8 A until 8 p.m. Calculate (*a*) the ampere-hour efficiency, and (*b*) the watt-hour efficiency of the battery for this cycle of operation. The terminal e.m.f. of each cell should be assumed to be 2·0 V (average) during discharge, and 2·25 V (average) during charge. Losses due to resistance are to be ignored.

Explain why the battery e.m.f. would not, in practice, remain constant during charge or discharge, and draw graphs of e.m.f. against time to indicate the variations that would be expected under the above practical conditions. (*C. & G. Telephony, Grade II*, 1946.)

5. In what circumstances is it desirable to make a cadmium test of a lead-acid secondary cell? Describe how the test should be performed and explain how faults in a cell would be revealed by the voltmeter readings obtained. (*C. & G. Telephony, Grade II*, 1945.)

6. What do you understand by the "rated ampere-hour capacity" of a lead-acid secondary cell? Describe how the total output in ampere-hours obtainable from (*a*) a dry cell and (*b*) a secondary cell, is affected by the rate of discharge. (*C. & G. Telephony, Grade II*, 1944.)

7. Describe briefly the construction and the special maintenance requirements of a counter e.m.f. cell as used in telephone exchange power plant. (*C. & G. Telephony, Grade III*, 1944.)

8. Draw a diagram of the connexions of a hand operated starter for a shunt-wound direct current motor. Explain the functions of the starting resistance and release coils. What factors determine the total value of the starting resistance? (*C. & G. Telephony, Grade II*, 1942.)

9. Draw a simple circuit diagram of either (*a*) a thermionic (Tungar) rectifier, or (*b*) a metal rectifier, charging plant suitable for a telephone exchange, and explain how full-wave rectification and voltage adjustments are obtained. (*C. & G. Telephony, Grade II*, 1945.)

10. A telephone exchange is served by two batteries each of 2000 Ah capacity, arranged for charge-discharge working. Give a circuit diagram of the connexions set up at the power board when one battery is supplying the exchange and the other battery is being charged.

At what stages during the charging of the battery would it be necessary to alter the voltage of the generator, and for what reasons? Specify suitable values of the charging current at the beginning and towards the end of the charge. (*C. & G. Telephone Exchange Systems I*, 1947.)

11. You are informed that the battery at a certain telephone exchange is "floating." Explain precisely what is meant by this. What advantages are gained by floating the battery? (*C. & G. Telephony, Grade II*, 1943.)

12. Describe the construction and mode of operation of an inductor tone generator. What factors determine the frequencies of the tone produced by the generator? (*C. & G. Telephony, Grade II*, 1944.)

CHAPTER XXI

MAINTENANCE AND FAULT TESTING

BROADLY speaking, the maintenance of telephone equipment may be considered under the two headings:

(*a*) The location and removal of reported faults.

(*b*) The prevention of faults by the systematic routine testing of plant and the removal of actual or potential faults before they interfere with service.

The efficiency of a telephone system is, to a large measure, judged by its freedom from equipment defects revealed in service. In the ideal case, all defects would be detected by routine tests before they interfered with service. In practice it is not possible to realize this ideal, but the aim of the maintenance organization should be:

(*a*) To obtain the lowest possible reported fault rate, i.e. the number of reported faults per telephone per annum should be a minimum.

(*b*) To minimize the time delay in the clearance of faults.

(*c*) To avoid "repeat faults," i.e. the recurrence of the same fault within a short period.

(*d*) To ensure that routine maintenance is effective by comparing the number of plant defects found by routine testing with the number of reported faults. The higher the ratio of routine faults to reported faults, the more successful is the routine maintenance.

In order to prepare the necessary statistics required for the control and direction of maintenance effort, it is necessary that records be kept of all faults (both reported and routine). A fault card is prepared for each exchange line, extension, junction, etc. In addition to full details of the make-up of the circuit, type of apparatus fitted, etc., the fault cards also show all faults or complaints together with the cause of each fault and the action taken to clear it. Dockets are also prepared for all exchange apparatus faults. It is possible from these primary records to maintain a complete fault history of the plant and to prepare any required statistics.

The most suitable type of maintenance organization depends upon a number of local conditions and particularly upon the density of telephone provision in the area. There are three main schemes known as:

(*a*) Detached Area organization.

(*b*) Maintenance Control organization.

(*c*) "ENG" Fault Complaint and Repair organization.

Detached Area Organization. The detached area scheme is suitable for an area where the exchanges are small and widely scattered or are so disposed as to render the centralized control of a number of maintenance officers uneconomical or otherwise unsatisfactory. The "detached area" is generally the territory maintained by one or perhaps two linemen. A convenient manual exchange (usually the exchange at the lineman's headquarters) is chosen as the *Fault Reporting Centre*, and all exchanges in the area report faults to this centre. Very often the Fault Reporting Centre is the parent exchange for a number of small unattended automatic exchanges, and the subscribers on these exchanges report all service troubles direct to the centre. Subscribers on other manual exchanges in the area report faults to the local operator who in turn passes forward details to the controlling exchange.

The officer in charge of the Fault Reporting Centre is aware of the exact territory of each faultsman in the area and distributes the faults accordingly. A daily summary of faults is prepared and is forwarded to a *Fault Recording Centre* where the details are entered upon the appropriate fault cards. Faultsmen in a detached area arrange their own programme of work, but instructions regarding routine tests to be carried out are forwarded periodically by the Fault Recording Centre who keep all records.

Maintenance Control Organization. When the telephone density is such that a number of maintenance staff are concentrated in a small area, an increase of efficiency can be obtained by centralizing the control of all maintenance work at one point known as the *Maintenance Control Centre*. At least one engineering officer is employed at the control centre and he is responsible for:

(*a*) the testing of circuits reported as faulty;

(*b*) the direction of linemen to specific work (both routine maintenance and faults);

(*c*) the maintenance of fault and routine test records;

(*d*) the scheduling of outstanding maintenance work, temporary repairs, etc.

The main difference between Detached Area and Maintenance Control working is that, in the latter organization, the movements of each maintenance officer are controlled from the central point. This enables the best possible co-ordination of work to be obtained, and should result in a material saving of travelling and a reduction in the time taken to clear faults.

ENG Service. Under Maintenance Control organization the subscriber reports all faults to his local operator who in turn reports to the supervisor of the exchange at which the Maintenance Control Centre is situated. "Fault Dockets" are then passed to the engineering maintenance control officer. In London and at certain provincial centres, arrangements are made for the subscribers to obtain direct access to the engineering repair organization by dialling "ENG" or a numerical code (e.g. 97). These circuits are terminated on the test desk (*q.v.*) at the Maintenance Control Centre, and complaints are dealt with by an engineering officer. ENG service is only applicable to large towns or cities and is limited to the subscribers on the main automatic and satellite exchanges in the area. Where it can be arranged, however, it has a number of advantages:

(*a*) The engineering staff receive details of faults immediately.

(*b*) The double handling of a complaint by the traffic and engineering staffs is avoided.

(*c*) The engineering officer who receives the complaint has the technical knowledge necessary to elicit full details of the trouble from the subscriber.

(*d*) Tests can be conducted with the co-operation of the subscriber.

(*e*) The engineering officer has access to the records of previous faults and complaints and of work done on the reported line. These records are often valuable in determining possible causes for the trouble reported.

Against these advantages it is sometimes argued that as subscribers are expected to report only *plant* defects to the engineering staff (service troubles being reported to the traffic staff), the need for discrimination between service and plant defects places too great a responsibility on the subscriber.

Maintenance Routines. Telephone apparatus is no different from any other mechanical equipment in that it requires periodical "serviceing" to ensure that it continues to function correctly. The prime object in giving such periodical attention is to locate and remedy faults, both actual and incipient, before they interfere with traffic. Systematic routine tests and inspections are therefore made of the equipment and such tests and inspections are known as *Maintenance Routines.* The testing apparatus used in making routine tests applies conditions which are more onerous than are likely to be encountered in use and therefore enables faulty operation of the equipment to be detected before it has interfered with the service. Successful routining will, when carried out sufficiently frequently, reduce considerably the number of cases giving rise to fault reports, and for this reason routines are an important part of an efficient maintenance organization.

There is, however, a large amount of telephone equipment in service, and the routine testing of the whole of this equipment necessitates the expenditure of a considerable amount of time. Too frequent routining will produce results incommensurate with the time spent, whereas, at the other extreme, routining at too long intervals will be reflected in an increased number of fault reports. The aim in routine testing must therefore be to strike the happy medium between the two extremes mentioned.

Exchange Routine Testing. Not all the equipment in an exchange is subjected to the same amount of use. For example, a subscribers' calling equipment may only be required to function, say, a half dozen or so times a day, whereas some portions of the "common" equipment may operate several hundreds of times during the same period. Moreover, the fault liability of various parts of the exchange equipment differs very considerably. The frequency at which routines are necessary therefore varies with the type of equipment. It is possible to determine the most effective routine frequency for each item of plant from the records of faults, etc. In a number of cases, standard periods are scheduled, and it is usual to follow these standard periods for the routines at all new exchanges. A little thought will show that slavish adherence to standard routine frequencies is not necessarily the most economical or desirable arrangement. If, for example, there are two exchanges of different ages, one might reasonably expect that the equipment at one exchange would require attention more frequently than that at the other. Again, there may be two exchanges with the same type of equipment, one of which is situated in an industrial locality with a heavy calling rate, whilst the other is in a residential district where the calling rate is low. It is clear that the economical routine frequencies will be vastly different in the two cases.

In the maintenance organization of the Post

Office, these considerations are taken into account by local modifications of the standard routine frequencies to meet the particular requirements of every exchange. During the life of an exchange, periodical fault analyses are made in order to determine the main sources of plant defects. As a result of this study, it is possible to plan for special overhauls, adjustment of the frequency of routines, or the introduction of new routines, with the object of improving the subsequent performance of the equipment. From an organization point of view, the principle of the variable routine period introduces some complications in the planning of the work, and there are some arguments for maintaining regular routine times except in very special circumstances.

Routine Tests of Subscriber's Apparatus. Faults on the subscriber's apparatus and line constitute a considerable proportion of the total plant faults of a telephone system. A number of these faults can be prevented by periodical routine inspections of the subscribers' installations. Such inspections, however, involve extra visits to the subscribers' premises, and materially increase the maintenance costs. At the present time, it is usual to carry out regular routine maintenance inspections only at subscribers' instalations where primary batteries are installed and also at the larger P.B.X. switchboards. No regular maintenance visits are paid to direct exchange lines connected to a C.B. or automatic system. (Call Offices and kiosks are an exception, and frequent maintenance visits are paid to such installations on account of the high volume of traffic from such lines.) It is nevertheless the standard practice for a faultsman, before leaving a subscriber's installation after removing a reported fault, to ensure that any obvious weaknesses that may give rise to faults in the near future are rectified. Such attention is known as *preventive maintenance* and, in a number of cases, is the nearest approach possible to regular maintenance routines.

Functional and Electrical Testing. Some telephone plant defects can be located as a result of a visual examination of the apparatus (e.g. a broken wire, a relay contact spring out of adjustment, etc., etc.). In other cases, the cause of a fault may be less apparent and may involve both functional and electrical tests to diagnose. If the fault is not detectable at the preliminary examination, it is usually necessary to carry out functional tests of the equipment to determine the exact nature of the failure. To facilitate such functional tests, it is a common practice to provide specially designed *test boxes* or *routiners*, which are arranged to apply test conditions somewhat more onerous than the conditions normally encountered in practice. Having determined, from functional tests, the particular phase of the circuit operation which is at fault, it is then necessary to locate the circuit elements concerned on the appropriate diagram of the apparatus. A further visual examination at this stage will often reveal the cause of failure, but if this is unsuccessful it may be necessary to carry out electrical tests of the portion of the circuit under consideration.

By far the greater proportion of telephone exchange and subscribers' apparatus faults can be found by means of simple direct current tests. Such tests will, in most cases, reveal not only faults on the signalling and switching circuits, but also a high proportion of faults which would affect speech transmission. In general, the most common defects are:

(*a*) A disconnexion or lack of continuity of the circuit.

(*b*) A short circuit either in the wiring or in one of the components.

(*c*) A low insulation or earth fault.

In all of these tests it is necessary to have some device which will indicate or measure the presence of an e.m.f. or current. The moving coil type of milliameter or voltmeter is highly suitable for the circuit testing of telephone equipment, and forms the basis of most testing instruments. A voltmeter of suitable sensitivity can be used in a wide variety of ways for the location of faults, but it is not possible in this volume to give more than a few of the more common and simpler uses.

Continuity Tests by means of Voltmeter. A voltmeter in conjunction with a suitable battery is possibly one of the best ways of locating a disconnexion in an electrical circuit. Assume (as in Fig. 638) that it is desired to test for and locate a disconnexion in a simple series circuit consisting of 5 contacts *A*, *B*, *C*, *D*, and *E*. If the voltmeter is connected to one pole of a suitable battery, and the second terminal of the battery is wired to one end of the series circuit, it is readily possible to locate any disconnexion by momentarily connecting the second terminal of the voltmeter to the circuit at positions 1, 2, 3, 6, 5, and 6 consecutively. When the voltmeter is connected to position 1, the full p.d. of the test battery will be recorded on the meter. If contact *A* is functioning correctly, then the same voltage will be recorded when the voltmeter is connected to position 2, and so on. If, now, the full voltage is recorded at position 3 but there is no reading when the voltmeter is connected to position 4, it is clear that contact *C* is at fault. It is often convenient to use the earthed

exchange battery for testing purposes. The same procedure can be followed by applying an earth to one end of the circuit and testing for this earth potential at successive points along the circuit (see Fig. 638). If one end of the circuit under test

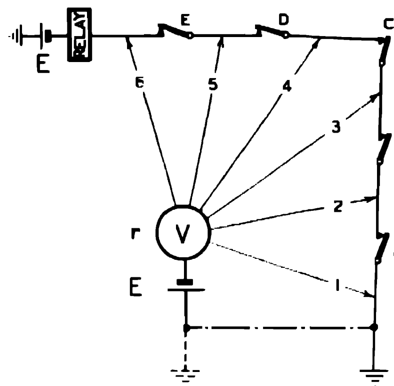


Fig. 638. Method of Carrying out Continuity Tests by means of Voltmeter

is connected to the exchange battery, then it may be more satisfactory to connect the voltmeter to earth instead of to battery.

A disconnexion may consist of a very thin film of a non-conducting material on the surface of a contact, and it is highly desirable, when testing for a disconnexion, to use the minimum possible e.m.f. in order to avoid breaking down the fault. It is also preferable to use a voltmeter of high resistance so that the current in the circuit under test is kept to a minimum. It would, of course, be possible to test for a disconnexion fault by inserting a milliameter or voltmeter in series with the circuit, and by systematically short-circuiting the various contacts which are suspected of being faulty. This method is in practice rarely used, since it involves the temporary disconnexion of the permanent wiring in order to insert the testing meter.

Measurement of Resistance by means of Voltmeter. It is sometimes necessary to measure the resistance of a circuit or of a component in order to test for the presence of a full or partial short circuit. The resistance of any component can usually be determined, with sufficient accuracy for most practical purposes, by means of a voltmeter and a suitable source of e.m.f. If the voltmeter, the battery, and the component under test are connected as a series circuit as shown in Fig. 639, then the current in the circuit is (from Ohm's Law):

$$i = E/(r + R) \text{ (amps)} \quad . \quad . \quad . \quad (1)$$

where E = e.m.f. of the battery (volts),
r = resistance of voltmeter (ohms),
and R = resistance under test (ohms).

By rearranging, it is clear that:

$$R = E/i - r \quad . \quad . \quad . \quad . \quad (2)$$

Usually, the values of E and r are known, and hence the value of the resistance under test can be calculated if the current in the circuit is measured. But, the reading of the voltmeter is directly proportional to the current through it. If, therefore:

D is the deflection of the voltmeter when the testing battery is applied directly to the voltmeter terminals, i.e. when the testing leads are short-circuited, and

d is the voltmeter deflection when the unknown resistance is in circuit,

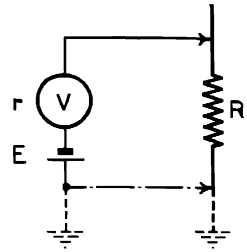


Fig. 639. Voltmeter Method of Measuring Resistance

then the ratio of the deflections is the same as the ratio of the currents in the two cases, i.e.

$$d/D = i/I,$$

where i = current with unknown resistance in circuit

and I = current without unknown resistance in circuit.

But

$$i = E/(r + R)$$

and $I = E/r$.

Therefore,

$$\frac{d}{D} = \frac{i}{I} = \frac{E/(r+R)}{E/r} = \frac{r}{r+R}.$$

Transposing,

$$R = (r \times D/d) - r,$$

i.e. $R = r(D/d - 1)$. . . . . (3)

When a large number of repetitive tests are to be carried out with the same battery and voltmeter, considerable time can be saved by calibrating the circuit and by preparing a chart showing the relationship between the testing battery voltage, the voltmeter readings, and the resistance values. Table X shows part of such a chart for a voltmeter of 2000 Ω resistance used in conjunction with a testing battery of from 7·6 to 8·0 V.

It is clear from an examination of the formula and of the tabulation that the sensitivity of the voltmeter method is determined by the

voltmeter resistance. If the voltmeter resistance were very high as compared with the test resistance, the former would swamp any change of current in the circuit. On the other hand, if the

TABLE X

PART OF VOLTMETER CALIBRATION CHART

Voltmeter Resistance $r = 2000\ \Omega$

Value of d	Value of R when D equals				
	7·6	7·7	7·8	7·9	8·0
0·1	150 000	152 000	154 000	156 000	158 000
0·2	74 000	75 000	76 000	77 000	78 000
0·3	48 666	49 333	50 000	50 666	51 333
0·4	36 000	36 500	37 000	37 500	38 000
0·5	28 400	28 800	29 200	29 600	30 000
.	.	.	.	.	.
.	.	.	.	.	.
4·8	1 167	1 208	1 250	1 292	1 333
4·9	1 102	1 143	1 184	1 224	1 265
5·0	1 040	1 080	1 120	1 160	1 200
5·1	980	1 020	1 059	1 098	1 137
5·2	923	962	1 000	1 038	1 077
.	.	.	.	.	.
.	.	.	.	.	.
7·5	27	53	80	107	134
7·6	0	26	53	79	105
7·7	—	0	26	52	78
7·8	—	—	0	26	51
7·9	—		—	0	25

resistance under test were very high compared with that of the voltmeter, the deflection would be unreadable. The most satisfactory arrangement is when the voltmeter resistance is approximately equal to the resistance under test.

Measurement of Insulation Resistance. The voltmeter method described above can be used

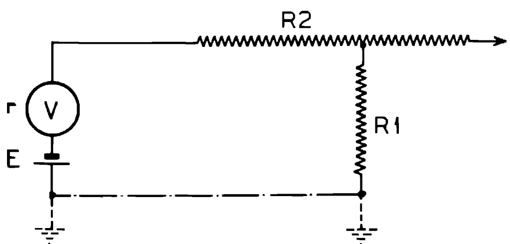


FIG. 640. MEASUREMENT OF INSULATION RESISTANCE BY MEANS OF VOLTMETER

for measuring the insulation resistance of a component or of a line. If, as in Fig. 640, earthed battery is connected to one terminal of the voltmeter and the circuit to be tested is applied to the second terminal of the voltmeter, the resistance to earth of the circuit under test can readily be

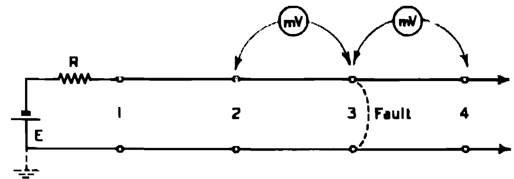


FIG. 641. POTENTIAL DROP METHOD OF LOCATING A SHORT CIRCUIT

calculated from the formula already given. If the insulation resistance between two conductors is to be tested, a reading can be obtained by earthing one of the two conductors. Alternatively, the testing battery can be connected to the second conductor instead of to earth, as shown by the broken line of Fig. 640.

It should be noted that the value obtained is the total resistance of the circuit to which the voltmeter is connected. If, therefore, as in Fig. 640, there is series resistance ($R2$) on the volt-

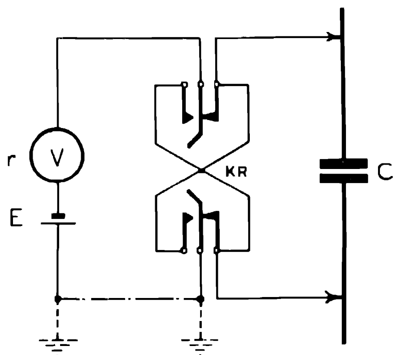


FIG. 642. VOLTMETER METHOD OF TESTING CONDENSERS

meter side of the low insulation fault, the value obtained is the combined resistance of $R1$ and $R2$. In most practical circumstances the insulation resistance is very high compared with the resistance of any series components, so that the value obtained by means of a voltmeter test is sufficiently accurate for most purposes.

In order to get a readable deflection with high resistance values, it is usually necessary to use a high voltage testing battery (e.g. 80 V). Moreover, in all cases where resistance measurements are made via earth connexions at two different points, it is important to make allowance for any difference of earth potential. The difference of earth potential

can usually be measured and should be added to or subtracted from the testing battery voltage before the resistance value is evaluated.

Location of Short Circuits. The presence of a short circuit or full earth fault in the wiring of exchange apparatus can readily be proved by simple continuity tests as already described. It is, however, somewhat more difficult to determine the exact *location* of the fault. In some cases it is convenient to disconnect the circuit at various

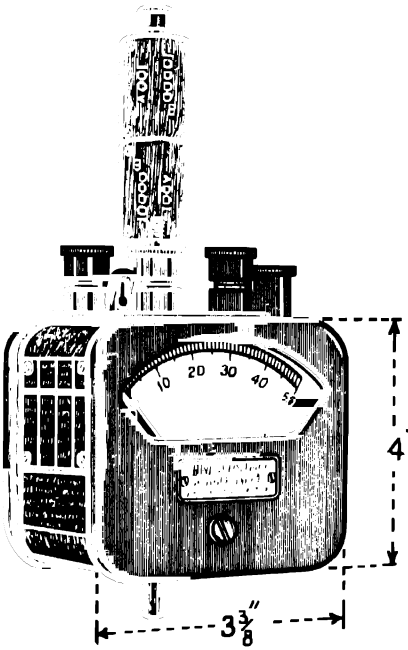


FIG. 643. POST OFFICE DETECTOR NO. 4 (shown with series resistors in position)

parts of the exchange and to determine the position of the fault by separate tests on each section of the wiring. In other circumstances this method may involve the unsoldering of permanent wiring, which is very undesirable.

The potential drop test illustrated diagrammatically in Fig. 641 is very useful for determining the position of a short circuit or earth fault, especially in circumstances where the circuit is looped into a number of different points (e.g. a switchboard or selector multiple). In principle a battery is connected through a suitable resistance (R) to the two wires affected. The current round the circuit produces a potential drop, the value of which is determined by the strength of the current and the resistance of the wiring. The conductors of the standard switchboard cable are usually of 23 S.W.G. copper wire, which has a resistance of some 0·0177 Ω per foot. If the current round the circuit is adjusted to, say, 250 mA then it is clear (from Ohm's Law) that there is a potential drop of some 4·425 mV per foot of the wiring. This potential drop can readily be detected by means of an ordinary commercial millivoltmeter with a sensitivity of 100 Ω per volt. A more sensitive meter would (with the same current) detect the potential drop over a few inches of switchboard wire.

If, as in Fig. 641, there is a contact fault between two conductors which are looped into apparatus



FIG. 644. TOP OF DETECTOR NO. 4 SHOWING TERMINALS AND ROTARY SWITCH

tags at points 1, 2, 3, and 4, the application of a millivoltmeter between tags 1 and 2, or between tags 2 and 3, will produce a deflection on the meter due to the potential drop in the circuit. When the meter is connected between tags 3 and 4, however, there is no potential drop, and it is clear that the fault is located at position 3. Occasionally a contact or earth fault occurs in the length of cable between two looping-in points (e.g. between tags 2 and 3). This condition will produce a lower reading of the voltmeter between terminals 2 and 3 than between 1 and 2, whilst the ratio of the two readings will give an approximate position of the fault between terminals 2 and 3. For example, if, under certain circumstances, a reading of 10 mV is obtained between terminals 1 and 2 and a reading of 5 mV is observed when the meter is connected between terminals 2 and 3, then the distance of the fault from terminal No. 2 is approximately equal to half the distance between terminals 1 and 2.

An ordinary telephone receiver provides a useful alternative means of detecting the presence of a potential drop in a conductor. A receiver of the 1L type (see Chapter III) will give a distinguishable click when it is connected to two points where there is a potential difference of 1 mV or more. The receiver can therefore be used in exactly the same way as a millivoltmeter to locate the position of a fault. Apart from its high sensitivity, a

receiver of the headgear type is more convenient than a millivoltmeter, and it is often used in preference to the latter for fault locations.

Testing of Condensers by Means of Voltmeter. Any condenser can be tested for insulation resistance by the methods described above. A condenser may, however, become disconnected internally and it is not possible to locate such a fault with the normal d.c. continuity tests. It is, how-

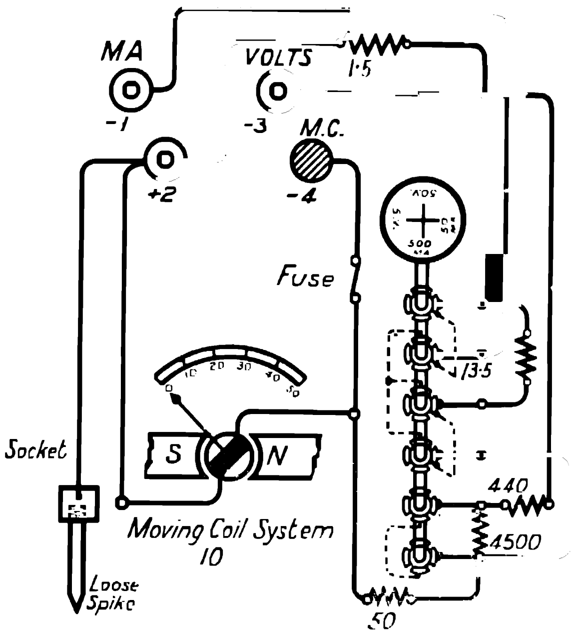


FIG. 645. INTERNAL CONNEXIONS OF DETECTOR No. 4

ever, possible to carry out a rough and ready check of a condenser by first charging the condenser and then allowing it to discharge through a voltmeter. Fig. 642 shows a suitable testing circuit. The key (*KR*) is so wired that the connexions to the condenser are reversed when the key is thrown. With the key in one position, a momentary deflection of the voltmeter occurs due to the charging current when the test leads are applied to the condenser. If the reversing key is now thrown, the battery potential applied to the condenser is reversed, and the resulting discharge and subsequent charging current flows through the voltmeter to give a momentary deflection. A rough check of the condenser capacitance can be made with almost any voltmeter, but if an accurate measurement of the capacitance is required, it is necessary to use a voltmeter of the "ballistic" type. Ballistic voltmeters are designed to have a minimum of electrical damping and a moving system with a large mechanical inertia. The deflection of such an instrument, resulting from a

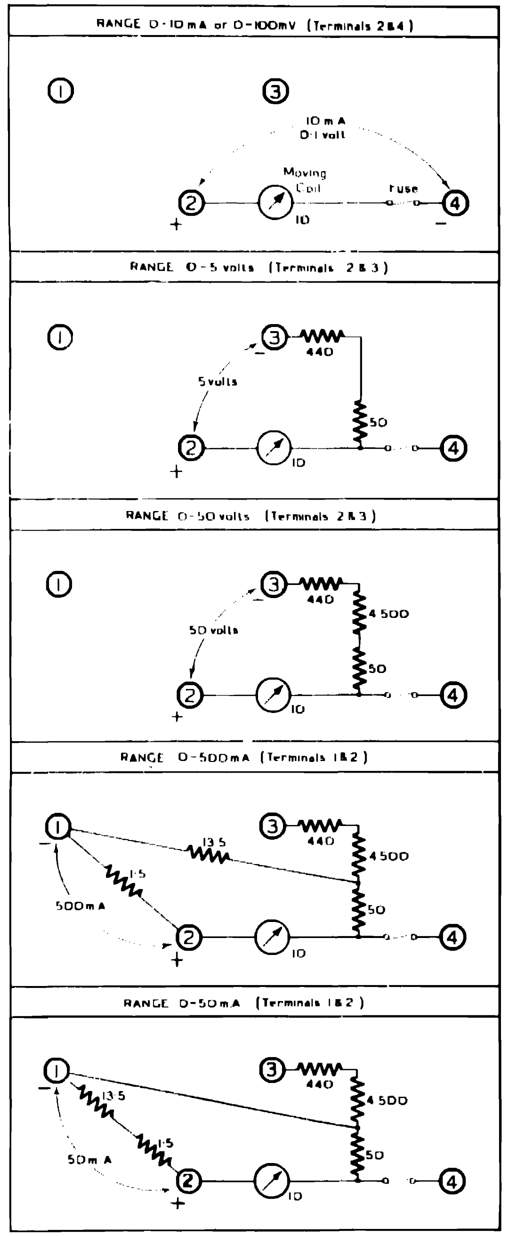


FIG. 646. THEORETICAL CONNEXIONS OF DETECTOR No. 4

surge of current through it, is proportional to the total *quantity* of electricity and is substantially independent of the rate of growth or decay.

When a ballistic voltmeter is used in the circuit of Fig. 642, the reading is directly proportional to both the voltage of the battery and the capacitance of the condenser ($Q = CV$). If, therefore, the instrument is calibrated with a condenser of known capacitance and with a testing battery of

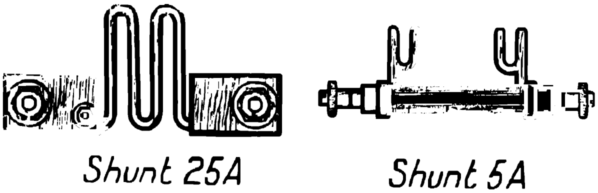


Fig. 647. Standard Shunts for Detector No. 4

known e.m.f., it is readily possible to determine the capacitance of any other condenser from a knowledge of the battery e.m.f. and the deflection obtained.

The circuit principles illustrated in Fig. 642 are used in practice for the testing of the condensers in subscribers' instrument circuits.

Detector No. 4. The standard general purpose testing instrument used in the Post Office is illustrated in Figs. 643 and 644. It is a combined ammeter and voltmeter of the moving coil permanent magnet type and, although it is small and light, it is of robust construction to withstand hard usage. The former of the moving coil system is of silver and is wound with silk insulated copper wire of 5 mils diameter. The moving coil system has a resistance of 10 Ω and gives a full scale deflection

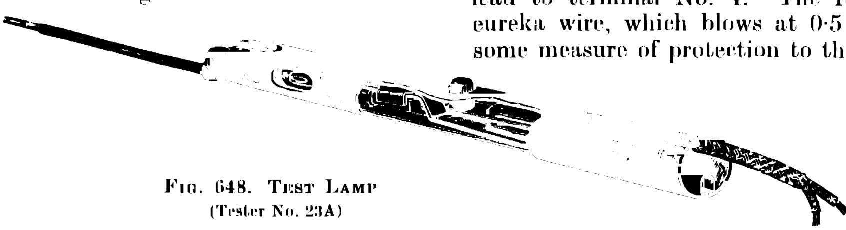


Fig. 648. Test Lamp
(Tester No. 23A)

with 0·1 V (i.e. 100 Ω per volt). The scale is substantially linear and is calibrated into 50 divisions, thereby giving a sensitivity of 2 mV or 0·2 mA per division.

The instrument has 4 terminals and a 4-position rotary switch which give the following ranges. The effective resistance of the instrument in each switch position is also indicated.

Current: 0 – 10 mA (10 Ω); 0 – 50 mA (12 Ω); 0 – 500 mA (1·47 Ω)

Voltage: 0 – 0·1 V (10 Ω); 0 – 5 V (500 Ω); 0 – 50 V (5000 Ω).

The internal connexions are given in Fig. 645, whilst the theoretical conditions for each range of the instrument are shown in Fig. 646. A feature

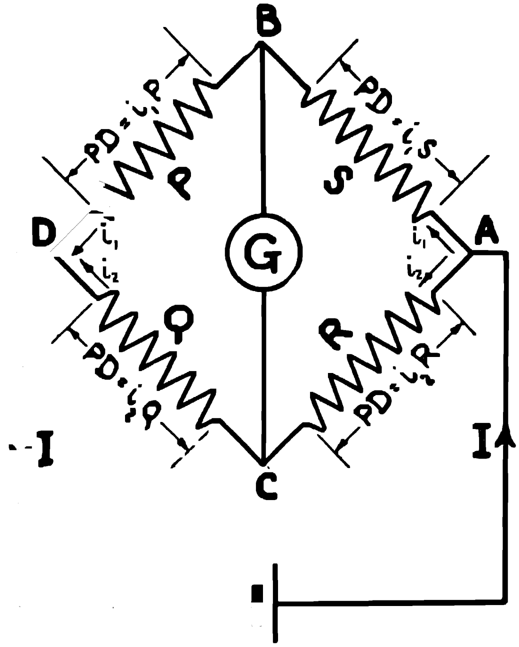


Fig. 649. Theoretical Circuit of Wheatstone Bridge

of the Detector No. 4 is the internal fuse in the lead to terminal No. 4. The fuse is of 2 mils eureka wire, which blows at 0·5 A, and provides some measure of protection to the moving system against accidental overload. The terminal connecting direct to the moving coil (No. 4) is also of a distinctive red colour as a further safeguard. A contact spike is provided with the detector and is normally housed in the back of the instrument. When required for such purposes as battery testing, it can be screwed into a socket in the base of the instrument and becomes a positive terminal.

The usefulness of the instrument is further increased by the provision of external shunts and series resistors to give additional ranges. The shunts (Fig. 647) are designed to bridge terminals 2 and 4 whilst the series resistors are screwed (one on top of the other) to terminal 3 (see Fig. 643).

By the use of these external units the following additional ranges are available:

5 A shunt: 0 — 5 A (0·02 Ω)
25 A shunt: 0 — 25 A (0·004 Ω)
1 series resistor: 0 — 150 V (15 000 Ω)
2 series resistors: 0 — 250 V (25 000 Ω)

Test Lamp. The test lamp illustrated in Fig. 648 is extensively used for simple point to point localization tests in a telephone exchange. Whilst it is not so sensitive as the voltmeter method of testing previously described, the test lamp provides a very convenient means of testing for the presence of earth or battery potential at any point in a circuit. The tester consists of an ebonite tube about ⅝ in. in diameter by approximately 6 in. long. An ebonite covered spike projects from one end and a jack is provided for a standard switchboard lamp. The tester is provided with a flexible cord which is terminated on a plug which can be inserted into a suitable "battery jack" on the apparatus rack. A press button type switch is so arranged that, in the normal position, battery is connected to one side of the lamp and the testing probe is connected to the other side of the lamp. By operating the press button, the battery is removed and earth is applied to one side of the lamp. With the press button in the normal position, the lamp will glow if the probe comes into contact with a conductor at earth potential. Similarly, with the press button operated, the lamp will glow when battery potential is encountered by the probe. A full earth (or battery) potential will cause the lamp to glow at full brilliance but, if the circuit under test contains resistance, only a partial glow is obtained. With a 50 V carbon filament lamp, the instrument will detect an earth or battery potential through a resistance of approximately 1500 Ω, whilst the value is increased to about 2000 Ω when a lamp of the metal filament type is fitted. This sensitivity is sufficient for most practical purposes, but if tests through higher values of resistance are required, resource must be made to the voltmeter method.

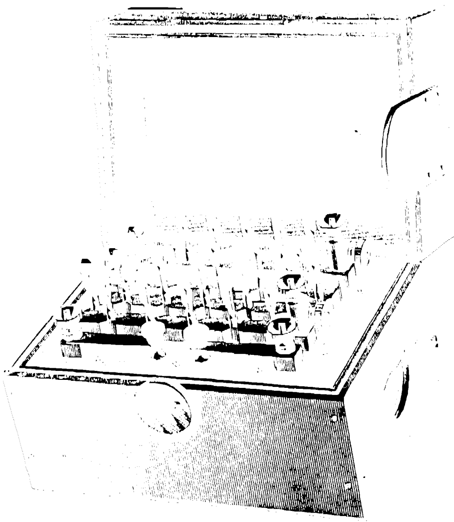


FIG. 650. P.O. BOX TYPE OF WHEATSTONE BRIDGE

Wheatstone Bridge. The principle of the Wheatstone Bridge is used extensively for the measurement of resistance, location of faults, etc. Fundamentally, the Wheatstone Bridge consists of four resistances (one of which being the unknown resistance) arranged in a diamond formation (Fig. 649) with a source of e.m.f. across one diagonal and a sensitive centre-zero galvanometer across the other diagonal. The resistance arms are adjusted to produce no deflection on the galvanometer, i.e. so that there is no potential difference between B and C.

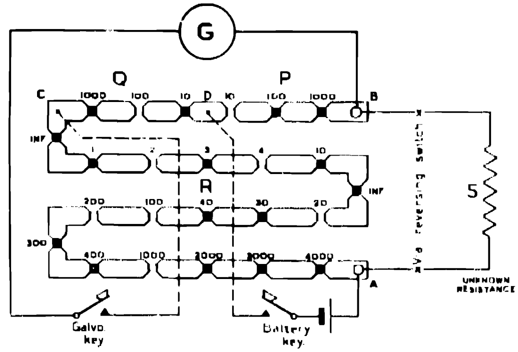


FIG. 651. INTERNAL CONNEXIONS OF P.O. BOX

The current (I) from the battery divides at A into two currents i_1 and i_2 through the upper and lower arms respectively. When the conditions are such that there is no potential difference across BC, the potential drop in S, due to i_1, is equal to the potential drop in R due to i_2. Similarly, the potential drop in P is equal to that in Q. But the potential drop is in each case (from Ohm's Law) given by the product of the current and resistance.

Thus:

$$i_1 S = i_2 R \qquad (1)$$

and $$i_1 P = i_2 Q \qquad (2)$$

Dividing (1) by (2),

$$\frac{S}{P} = \frac{R}{Q} \text{ or } \frac{S}{R} = \frac{P}{Q} \qquad (3)$$

Thus if any three of the resistance elements are known (say *P*, *Q*, and *R*) it is readily possible to calculate the value of the fourth unknown resistance (*S*). To obtain the correct balance against an unknown resistance, at least one of the known resistances must be variable. By providing facilities for altering the ratio of the two remaining

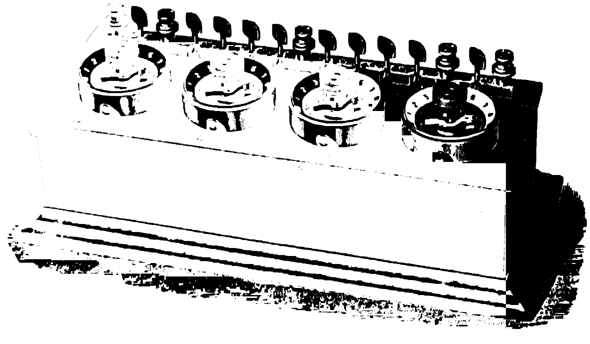


FIG. 652. DIAL PATTERN BRIDGE

resistances it is possible to obtain a very wide range of measurement. The sensitivity of the arrangement is to some extent dependent upon the resistance of the galvanometer relative to the resistance of the remaining bridge elements. For the maximum sensitivity, the galvanometer resistance should be comparable with that of the resistance elements.

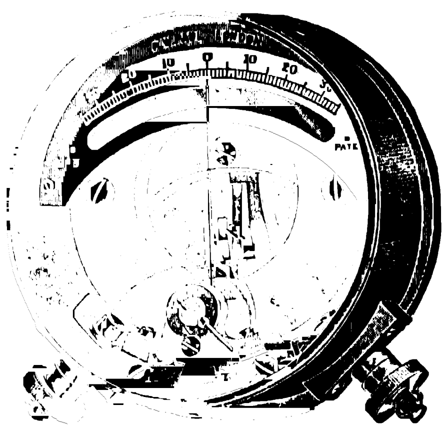


FIG. 653. UNIPIVOT GALVANOMETER

Wheatstone Bridge Apparatus. The well-known "P.O. Box" type of Wheatstone bridge is illustrated in Fig. 650. The resistances are in the form of non-inductively wound coils connected to brass strips on the top of the instrument. Tapered brass plugs are provided which can be inserted between the strips to short-circuit the coils as desired. Galvanometer and battery keys together with reversing switch complete the unit. The value of the resistance coils and the general arrangement of the box are illustrated in Fig. 651. The letters refer to the equivalent parts of the theoretical circuit (Fig. 649). The arms *P* and *Q* are known as the *ratio arms*, and the plugs can be arranged to produce resistance ratios of 1/1, 10/1, 100/1, 1/10, and 1/100. The variable resistance arm *R* can be adjusted from 1 Ω up to a maximum of 11 110 Ω Thus, by utilizing the ratio arms in conjunction with *R*, it is possible to balance against an unknown resistance of from 0·01 Ω to 1 111 000 Ω. Fig. 651 shows a typical arrangement of plugs to balance against a test resistance of 132·6 Ω. A *P*/*Q* ratio of 1/10 is used in this particular case.

The P.O. Box type of bridge has now been largely superseded by the dial type of bridge (Fig. 652) for field work. The principle is identical but the replacement of the plugs in the variable resistance arm (*R*) by rotary switches with direct reading dials makes the instrument easier and quicker to use.

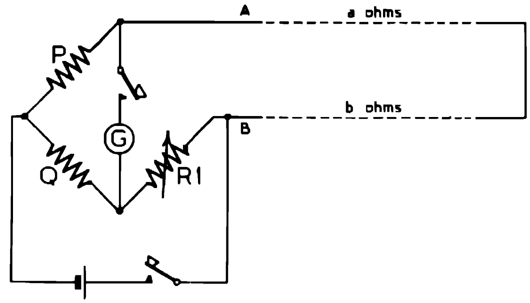


FIG. 654. BRIDGE MEASUREMENT OF LOOP RESISTANCE OF A LINE

Any sensitive centre-zero galvanometer may be used with the Wheatstone Bridge. Fig. 653 shows the general appearance of the unipivot type of galvanometer commonly used with the bridge. It is a permanent magnet moving coil instrument with a resistance in the order of 50 Ω and will give a full scale deflection with a current of 0·1 mA.

Bridge Measurement of Line Resistance. The loop resistance of a telephone pair can be measured with a high degree of accuracy by means of a Wheatstone Bridge as shown in Fig. 654. *P* and *Q* are the ratio arms of the bridge and *R*1 is the variable resistance. The fourth arm of the bridge (*S*) is made up of the *A* and *B* wires of the line under test which are looped at the distant end. With equal values of resistance in the ratio arms (*P* and *Q*) the variable resistance (*R*1) is gradually increased until there is a minimum deflection on the

galvanometer when the battery and galvanometer keys are operated. A telephone line has an appreciable value of line-to-line capacitance and, even when the bridge is balanced from a d.c. point of view, there is a surge of current through the galvanometer each time the battery key is operated. It is therefore important to ensure that the galvanometer deflection has attained a steady value before a reading is taken, otherwise false results

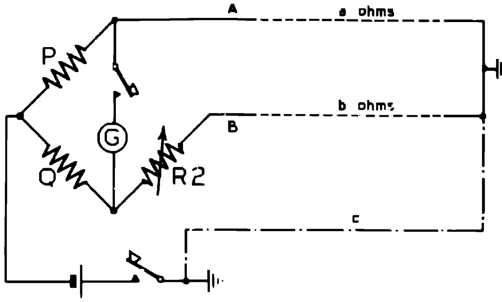


FIG. 655. MEASUREMENT OF SINGLE CONDUCTOR RESISTANCE OR OUT OF BALANCE RESISTANCE

will be obtained. After the approximate resistance has been determined from initial tests with equal ratio arms, it is possible, if desired, to measure the loop resistance to a higher degree of accuracy by varying the ratio of arms P and Q as already explained.

It is sometimes necessary to measure the resistance of the individual wires of a pair, or to know the extent of resistance unbalance between the wires of a telephone loop. The bridge circuit shown in Fig. 655 can be used for such tests. One pole of the testing battery is now earthed and the telephone wires are looped and earthed at the distant end. If the resistances of the two wires of the loop are a and b, then it is clear from the previous considerations that in the balanced condition:

$$\frac{P}{Q} = \frac{a}{b + R2}$$

If the ratio arms (P and Q) are of equal resistance, then

$$R2 = a - b \qquad . \quad . \quad . \quad (1)$$

But $a + b$ is the loop resistance of the pair and can be measured as shown in Fig. 654. If the reading obtained for the loop resistance is $R1$, then

$$R1 = a + b \qquad . \quad . \quad . \quad (2)$$

From (1) and (2) it is clear that the individual resistances of the two wires are:

$$a = \frac{R1 + R2}{2} \qquad . \quad . \quad . \quad (3)$$

and

$$b = \frac{R1 - R2}{2} \qquad . \quad . \quad . \quad (4)$$

If, with the circuit arranged as in Fig. 655, the bridge cannot be balanced by adjusting $R2$, it indicates that the resistance of the B wire is greater than that of the A. If this occurs, it is necessary to reverse the connexions of the A and B wires to the bridge in order to obtain a balance.

In order to obtain the desired degree of accuracy, it is often necessary to carry out the tests with unequal ratio arms. It is usually convenient to retain the same values in the ratio arms for both tests. If the ratio arms are P and Q, then:

$$R1 = (a + b) \times Q/P \text{ (Fig. 654)} \quad . \quad (5)$$

and

$$R2 = (a \times Q/P) - b \text{ (Fig. 655)} \quad . \quad (6)$$

from which

$$b = \frac{R1 - R2}{1 + Q/P} \qquad . \quad . \quad (7)$$

When the value of b is known, a can readily be calculated from (5).

In some circumstances variable earth potentials make it difficult to obtain reliable test results. In these circumstances it is generally preferable to utilize a third wire (c) instead of the earth connexion as shown by the broken line in Fig. 655.

When three wires are available, it is possible to determine the conductor resistance of each

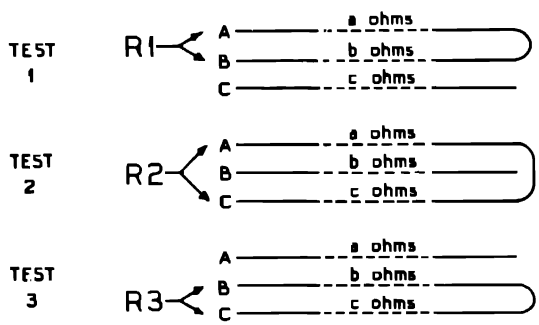


FIG. 656. THREE-TEST METHOD OF MEASURING THE RESISTANCE OF INDIVIDUAL LINE CONDUCTORS

individual wire by three separate loop resistance measurements. If the three wires to be tested are designated A, B, and C, it is possible to form three loops, i.e. $A + B$, $A + C$, and $B + C$. If, now, a, b, and c are the resistances of the three wires A, B, and C respectively, and $R1$, $R2$, and $R3$ are the three loop resistances obtained (Fig. 656), then:

From 1st test, $R1 = a + b$ . . . (8)

,, 2nd test, $R2 = a + c$ . . . (9)

,, 3rd test, $R3 = b + c$ . . . (10)

By adding (8) and (9),

$$2a + b + c = R1 + R2 \qquad . \quad . \quad (11)$$

By subtracting (10) from (11),

$$2a = R1 + R2 - R3,$$

from which

$$a = \frac{R1 + R2 - R3}{2} \qquad . \quad . \quad (12)$$

Subtracting (12) from (8),

$$b = \frac{R1 - R2 + R3}{2} \quad . \quad . \quad (13)$$

Similarly, by subtracting (12) from (9),

$$c = \frac{R2 + R3 - R1}{2} \quad . \quad . \quad (14)$$

Hence the individual resistance of each of the three wires is obtained.

Varley Test. Fig. 657 shows the connexions of a Varley test for the location of an earth or contact line fault. Before the test can be commenced, it is necessary to select one wire which has a high value of insulation resistance (known as the *good wire*) and to loop this good wire with the faulty wire at the

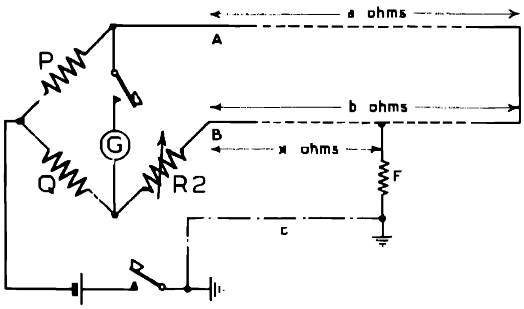


Fig. 657. Simple Varley Test for the Location of a Low Insulation or Contact Fault

distant end. The loop resistance of the pair thus formed is first measured with the circuit arranged as in Fig. 654. The battery is then connected to earth as shown in Fig. 657, and the bridge is again balanced. If the ratio arms are equal and

a = resistance of good wire (ohms),
b = resistance of faulty wire (ohms),
x = resistance of line up to low insulation fault,
$R1$ = loop resistance measurement (Fig. 654),
$R2$ = Varley measurement (Fig. 657),

then

$$R1 = a + b \quad . \quad . \quad . \quad . \quad (1)$$

and

$$R2 = a + b - 2x, \quad . \quad . \quad . \quad (2)$$

from which

$$x = \frac{R1 - R2}{2} \text{ (ohms)} \quad . \quad . \quad (3)$$

This equation holds good whether or not the two wires of the loop are of equal conductor resistance. If the faulty wire (b) is of uniform gauge throughout its length, then it is readily possible to determine the distance of the fault from a knowledge of the resistance per mile of the conductor.

If unequal ratio arms are used for the Varley te then the formula for the fault location is given b

$$x = \frac{L - nR2}{n + 1} \text{ ohms} \quad . \quad . \quad . \quad ($$

where L = loop resistance (ohms),
$R2$ = Varley measurement,
n = ratio P/Q.

If the ratio arms are maintained constant throughout both the loop and the Varley tests, then

$$x = \frac{n(R1 - R2)}{n + 1} \text{ (ohms)} \quad . \quad . \quad (5)$$

where $R1$ = loop measurement (Fig. 654)
and $R2$ = Varley measurement (Fig. 657).

It will be noted that in the Varley circuit there are two earth connexions. Variable earth potentials between these points may interfere with the tests, but the difficulty can be overcome by connecting the battery to a second faulty wire (c) instead of to earth, thereby using only the one earth connexion (at the fault).

The simple Varley test enables an earth fault to be located with accuracy if the insulation resistance of the good wire is very high compared with that of the faulty wire. Somewhat more elaborate variations of the Varley test have been designed for use in circumstances where it is difficult to obtain a "good" wire of high insulation resistance and also for the location of insulation faults of high resistance.

The procedure and methods described above for calculating the distance of an earth fault can also be used for determining the location of a

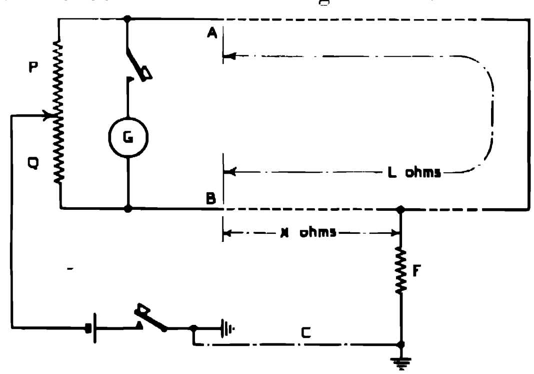


Fig. 658. Murray Test for the Location of a Low Insulation or Contact Fault

contact between two wires. For such tests the battery is connected to the wire which is in contact with the faulty wire instead of to earth.

Murray Test. The Murray test is an alternative method of locating an earth or a contact fault, and is particularly suitable for use on short lines.

In practice it is used mainly for locating the exact position in a short length of cable of a fault which has been located approximately by means of a Varley or similar test. The circuit connexions of the Murray test are as shown in Fig. 658. As before, a good wire is required which is looped to the faulty wire at the distant end. The separate resistance arm ($R2$) of the Varley test is not used, but a balance is obtained by means of a slide wire which forms variable ratio arms (P and Q).

As in the Varley test, the loop resistance of the pair is first measured and the connexions then arranged as in Fig. 658. If L is the loop resistance, then the resistance (x) to the fault is given by

$$x \text{ (ohms)} = \frac{Q}{P+Q} \times L \qquad . \qquad . \quad (1)$$

Where a slide wire is used, the value ($P + Q$) is constant (say, S ohms) and the equation can be written

$$x = Q/S \times L \qquad . \qquad . \qquad . \quad (2)$$

If the loop resistance of the circuit under test is low, the maximum sensitivity can be obtained by the use of a slide wire of low resistance (e.g. 200 Ω or 40 Ω). In these circumstances the effect of the resistance of the leads from the cable to the slide wire must be considered.

The Murray test can also be applied for locating the position of a contact fault between two conductors. The circuit arrangements are substantially similar, except that the second faulty conductor (C) replaces the earth connexions in Fig. 658.

The Megger. The "Megger" is the trade name of Evershed & Vignoles, Ltd., for a series of instruments specifically designed for the measurement of resistance. (Such instruments are often known as "ohmmeters.")

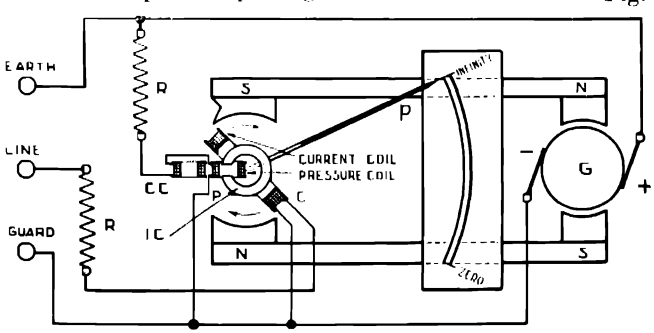


FIG. 659. INTERNAL CONNEXIONS AND GENERAL ARRANGEMENTS OF THE MEGGER

The Megger consists of a direct current generator, and a special moving coil instrument contained within a single case. The generator has a permanent magnet field system, which also serves the moving coil assembly. The generator which is usually of 250 or 500 V, is driven through gearing by the turning of the instrument handle or, in some models, by means of an electric motor. A centrifugal clutch is provided on most of the instruments used in telephony, and is adjusted to slip when the handle is turned at more than 100 r.p.m. By this means, the generator speed (and hence its voltage) can be maintained substantially constant. In this connexion, it should be noted that the mechanism of the instrument is such that the reading obtained is independent of the voltage of the generator. Constancy of e.m.f. is, nevertheless, required to avoid surge currents which would upset the readings when tests are being made on circuits containing inductance or capacitance.

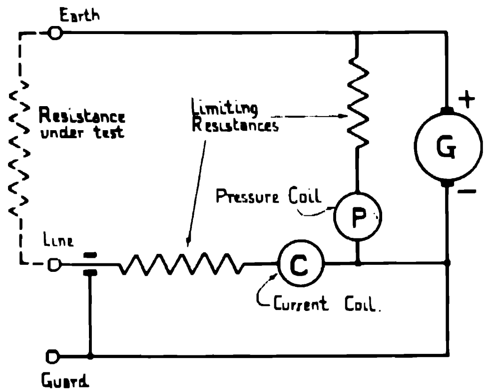


FIG. 660. SCHEMATIC DIAGRAM OF MEGGER CIRCUIT

Fig. 659 shows the general arrangements of the Megger, whilst Fig. 660 gives the circuit in schematic form. The moving element consists essentially of two coils rigidly secured at an angle to each other, and the assembly is pivoted to move about a common axis (Fig. 661). There is, in practice, a third coil, the function of which is described later. The coils are supported on metal frames in which eddy currents are induced during movement of the system, thereby causing the movement to come to rest quickly. The connexions to the moving coils are made through thin phosphor bronze ligaments, which are carefully balanced so that there is no resultant torque on the moving system, i.e. there is no appreciable restoring force to make the pointer come to rest in any particular position. One of the two main coils is known as the *control* or *pressure* coil, whilst the second is the *deflecting* or *current* coil. The coils

are so connected that, when current flows through them, the torques developed are mutually opposing.

The principle of operation is shown more clearly in Fig. 662. The left-hand portion (A) of the illustration shows the position of the coils when the pointer is at the "infinity" position, whilst the right-hand part (B) of the diagram shows the position of the coils when the pointer is at the low resistance end of the scale. When a current of any

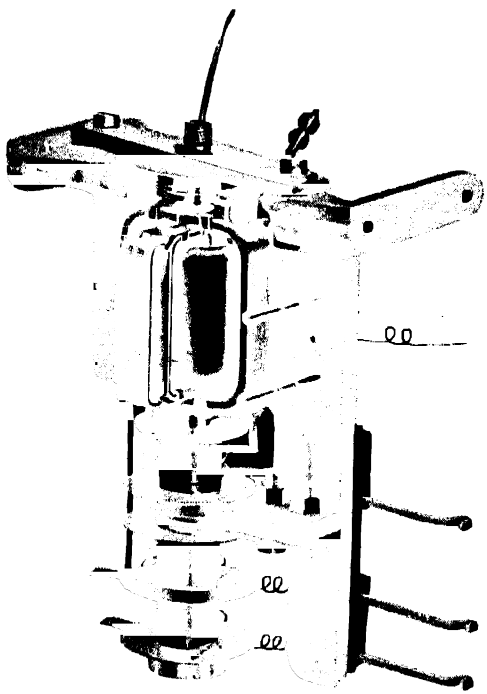


FIG. 661. MOVING COIL SYSTEM OF MEGGER

value is flowing in the pressure coil, but no current is flowing in the current coil, the moving element sets itself with the pressure coil at right angles to the magnetic flux. This corresponds to the infinity position of the instrument pointer, and the shape of the magnetic field is such that, under these conditions, the moving system is in stable equilibrium. If, for any reason, the moving system is displaced from this position, the pressure coil develops a restoring torque due to its axis being at an angle to the flux. It should be noted that the conductors on the inner side of the pressure coil contribute nothing to this torque, because they lie along the axis of rotation, and they are moreover in a very weak magnetic field due to the presence of the soft iron ring. The restoring torque on the pressure coil increases progressively as the system is displaced from the infinity position. This increase is due, partly to the increasing angle between the axis of the coil and the direction of the flux, and also due to the increase of field strength as the coil comes more and more under the influence of the pole tip. The pressure coil is therefore somewhat analogous to the spring in the ordinary type of moving coil instrument. The increase of torque, as the deflection is made greater, can be adjusted in the design of the instrument, according to the type of scale required.

The current coil can be considered as equivalent to the working coil of a moving coil ammeter. Any current through it tends to turn the moving element against the restoring torque of the pressure coil until it reaches a position where the two torques balance each other. The pointer, therefore, comes to rest at a position determined by the ratio of the currents in the two coils. The pressure coil is connected through a fixed resistor to the generator output, and hence, since the resistance of this circuit is constant, the current in it is proportional to the e.m.f. generated. The circuit of the current coil (Fig. 660) includes the resistance under test, and the current through it is therefore dependent, firstly upon the e.m.f. of the generator, and secondly upon the value of the external resistance. The e.m.f. is common to both circuits, and hence the ratio of the currents is independent of the generator e.m.f., and is determined solely by the value of the external resistance.

When no current is flowing in the current coil (e.g. when the tester is indicating infinite resistance), the outer limb of the pressure coil is in a relatively weak magnetic field. There is, therefore, a danger of interference by any stray magnetic fields. Most ohmmeters are fitted with a *compensating* coil to counteract these effects. The compensating coil consists of an additional control coil mounted in the same plane as, but beyond, the normal pressure coil, and is connected in series with the latter. The connexions are such that any outside magnetic field produces equal and opposite torques in the compensating and pressure coils.

A typical Megger instrument of modern design is illustrated in Fig. 663.

Use of Guard Terminal. In some circumstances, false insulation resistance readings may be obtained due to surface leakage currents. Most ohmmeters with a high resistance range are fitted with a *guard terminal* to minimize such errors. The guard terminal is connected direct to the negative side of the generator (Fig. 660), and any current flowing in this circuit does not pass through the current coil. If the guard terminal is connected

near the ends of the insulation of the conductor under test, as shown in Fig. 664, any surface leakage currents return via the guard lead, and hence the reading obtained is the true resistance of the dielectric. The guard terminal is also connected internally to a metal ring surrounding the line terminal of the Megger itself. This guard and the adjustable resistor form three arms of the bridge, which is completed by the resistance under test. The current coil of the ohmmeter serves as the galvanometer and the control force is provided by the pressure coil which is independently supplied from the generator terminals. When no current passes in the current coil, the force exerted

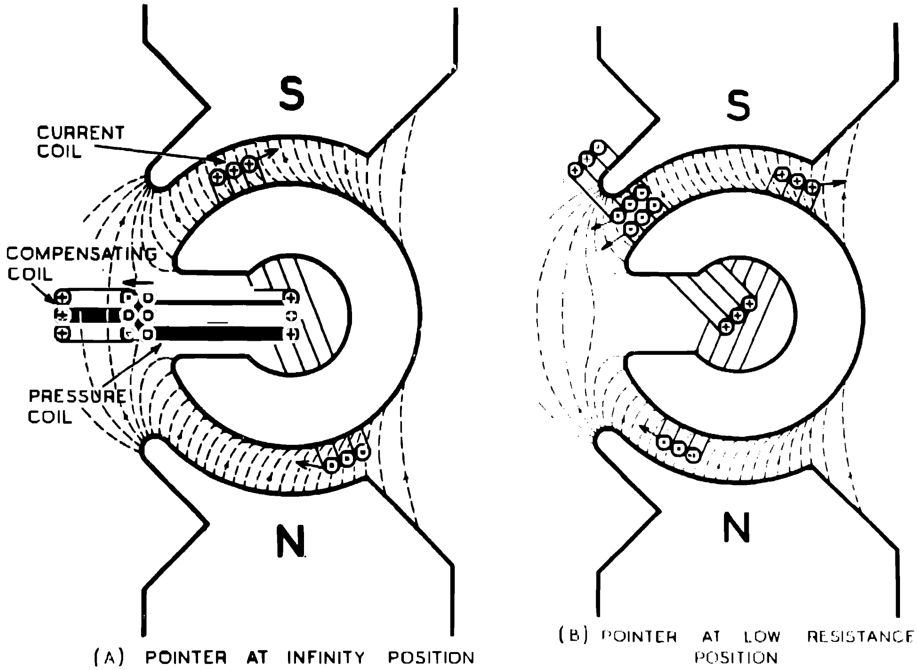


Fig. 662. Diagrammatic Representation of Action of Megger

ring prevents errors due to leakage currents along the surface of the instrument case.

The Bridge Megger. The Bridge Megger is an instrument combining the normal functions of an ohmmeter with those of a Wheatstone Bridge. There are several different models. Fig. 665 shows a modern type (P.O. Ohmmeter No. 6), which includes a 4-dial variable resistor unit of the "decade" type. A rotary switch changes over the internal connexions to "Megger," "Bridge," or "Varley" as required, whilst a second switch gives 5 ratio arm values (1/100, 1/10, 1, 10, and 100). The case is of aluminium alloy, the lid and base being of moulded synthetic resin.

When used as an insulation tester, the instrument is exactly similar to the ordinary Megger already described.

When the changeover switch is set to "Bridge" the circuit is arranged in the form of a Wheatstone Bridge as shown in Fig. 666. The two ratio arms by the pressure coil brings the pointer to the "Infinity" position. The infinity reading therefore corresponds to a balanced condition of the bridge.

Before commencing bridge tests it is important to check that the true point of balance is at the infinity mark. To do this, the switch is turned to the "Megger" position and with the terminals disconnected, the handle is turned at the correct speed. If necessary, the pointer should be set to the infinity mark by means of the adjusting screw provided. After setting the pointer, the resistance to be tested is connected to the Line and Earth terminals, and the changeover switch is moved to "Bridge." The ratio switch is set at "1," and each resistance dial is turned to "0." The handle is now turned while raising the resistances step by step, first the thousands, then the hundreds, tens and units, successively, until the pointer shows a balance by resting at infinity. The value of the resistance is shown by the indicators of the resistor

dials. If the resistance proves to be below 1000 Ω, the ratio switch should be set at 1/10 and a new balance obtained. The value of the resistance is now equal to the reading of the dials divided by 10. Similarly, to measure a resistance below 100 Ω with the greatest precision, the switch is set at 1/100. For resistances above 9999 Ω, the 10 times ratio is

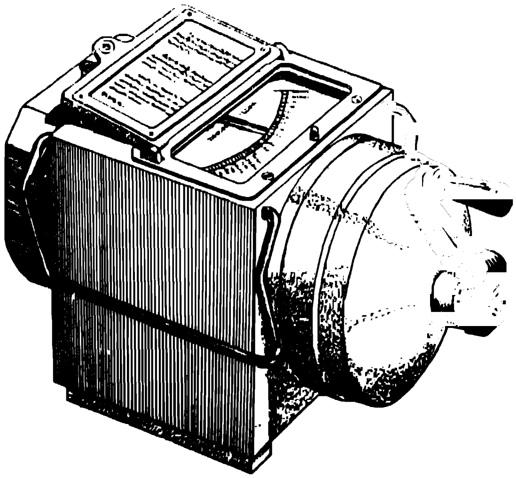


Fig. 663. A Typical Megger Instrument of Modern Design

used, or if above 99 990 Ω the 100 times ratio is required.

To localize an earth fault, the faulty line is connected to the Earth terminal and a good line,

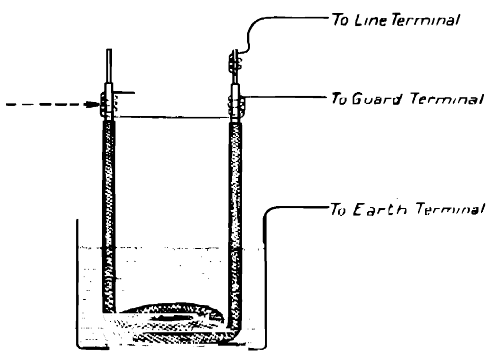


Fig. 664. Use of Guard Wire to Prevent Errors Due to Surface Leakage

which is looped to the faulty one at the far end, is connected to the Line terminal. The Varley Earth terminal of the instrument is wired to a good earth. The changeover switch is first set to Bridge and the total resistance of the loop is measured as described above. The changeover switch is now turned to Varley and a balance is again obtained. The distance in ohms to the faul is given by the equations already set out for th various Varley Loop tests.

Bridge Meggers based on the principles des cribed are also available with a mains rectifier uni in place of the d.c. generator. These instrument are more applicable to fixed locations such a



Fig. 665. Bridge Megger

Trunk Test racks (*q.v.*) or for the acceptance testing of new exchange equipment, etc.

Location of Disconnexions. Possibly one of the most satisfactory methods of locating a discon-

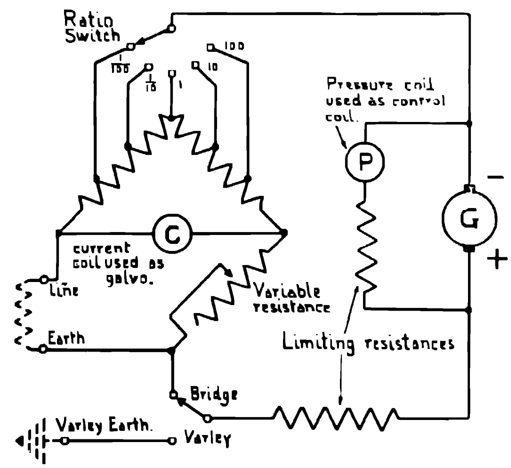


Fig. 666. Circuit of Bridge Megger

nexion fault on a short length of unloaded cable is by means of the a.c. slide wire. The a.c. power supply to the bridge is generally of a frequency between 500 and 1000 c/s, and is obtained either

from an oscillator or a mechanical buzzer. The principle of the method depends upon the fact that (on short lines) the impedance of the pair up to the disconnexion, and the impedance of the loop from the disconnexion via the far end, are inversely proportional to the capacitances of these paths. The circuit arrangements are shown in Fig. 667, and if L is the total length of the section under test and x is the distance of the fault, then

$$x \text{ (miles)} = \frac{Q}{P+Q} \times 2L.$$

The transformer used must be screened and the windings must be balanced to earth. The test leads must also be individually screened in order to minimize the wire-to-wire capacitance of the leads.

On long cable sections, and particularly on loaded cables, the inductance and resistance of the cable conductors have a material effect on the impedance of the circuit at speech frequencies. The assumptions made in the above test are, therefore, not justified in these circumstances. One method of avoiding errors is to utilize a very low-frequency alternating current (for example, the output from a hand generator). At such low frequencies, the inductive reactance of the line

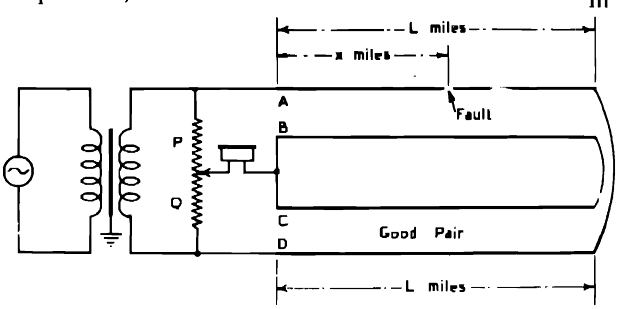


FIG. 667. A.C. METHOD OF LOCATING A DISCONNEXION FAULT ON SHORT UNLOADED LINES

is very small compared with the reactance due to the line capacitance, and a reasonably accurate location of a fault can be obtained with the circuit of Fig. 667. When a low-frequency supply is used, a telephone receiver is unsuitable for the detection of out of balance currents. One method of overcoming this difficulty is to include in the receiver circuit a pair of interrupter contacts which are mechanically driven at audio frequency. Alternatively, a galvanometer, suitably equipped with rectifiers for the detection of alternating currents, may be used in place of the receiver.

When very low-frequency alternating current is employed, a fixed condenser of known capacity can be used in place of the good pair in Fig. 667. Errors will occur with this arrangement unless the insulation of the line under test is comparable with that of the condenser. If this does not obtain, then it is necessary to balance the bridge with the aid of a variable high resistance connected across the fixed condenser.

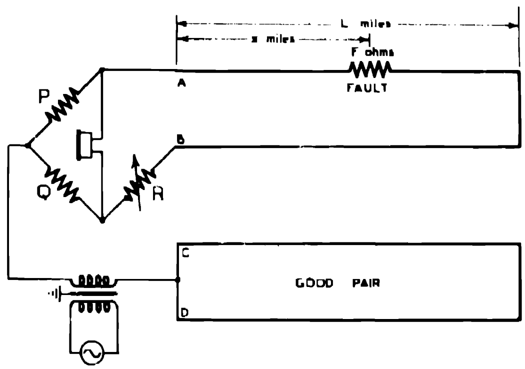


FIG. 668. REID TEST FOR THE LOCATION OF A HIGH RESISTANCE CONDUCTOR FAULT

Location of High Resistance Faults. A useful circuit for the location of a high resistance fault in one wire of a cable pair is the Reid test shown diagrammatically in Fig. 668. The resistance of the fault is first measured by means of a suitable circuit (e.g. Fig. 655), and the faulty pair is then looped at the distant end. A good pair, similarly looped at the distant end, is also required. If the ratio arms (P and Q) are equal, and

F (ohms) = resistance of the fault,
L (miles) = length of the section under test,
x (miles) = distance of fault from testing end,
R (ohms) = reading obtained,

then

$$x = L\,(1 - R/F).$$

In order to ensure accuracy, it is important that the source of alternating current and the transformer should be well separated from the rest of the apparatus, and also that the testing leads should be as short as possible.

There are various direct current methods of locating high resistance or disconnexion faults. In some of these methods the circuits are substantially similar to those given in Figs. 667 and 668, but a reversible battery is used in place of the source of alternating current. In these circumstances a ballistic galvanometer is necessary to detect out of balance conditions.

Earth Testing. The earth system at an exchange or at a subscriber's premises can readily be tested with a battery, voltmeter and ammeter connected to two earth spikes P and C as shown in Fig. 669. The current electrode (C) should be at least 30 yd from the earth to be tested (E) and the potential electrode (P) should be approximately half way between these two. The battery and ammeter are connected in series to produce an earth current of known value between E and C. It is clear that the voltmeter connected between the main earth and the electrode P will measure the potential drop in the earth due to this current. From Ohm's

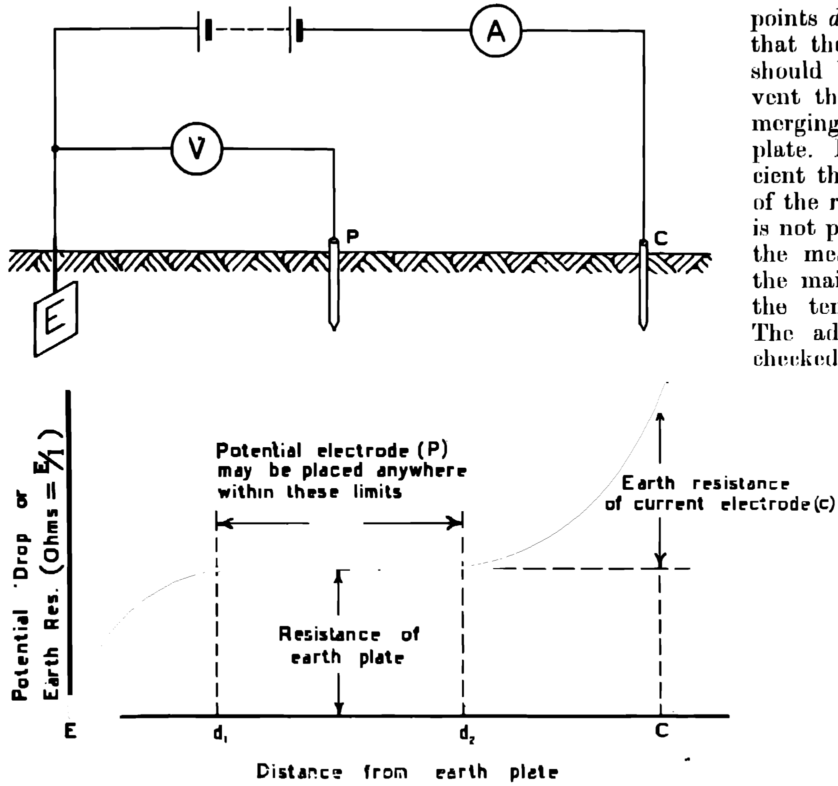


FIG. 669. MEASUREMENT OF EARTH RESISTANCE BY MEANS OF VOLTMETER AND AMMETER

Law the earth resistance from E to P is therefore E/I where E is the voltmeter reading and I is the current in the circuit.

If measurements are taken with electrode P at various distances from the main earth, the earth resistance will be found to increase up to a certain point d_1 (Fig. 669), then to remain steady up to d_2 with a final sharp rise of resistance from d_2 up to C. The value from E to d_1 is the resistance of the main earth plate whilst that from d_2 to C is the earth resistance of the temporary electrode C. The earth resistance of any buried plate or spike is determined by the resistivity of the soil immediately surrounding it. The circle formed by the radius $E - d_1$ is known as the *resistance area* of the earth electrode E, the extent of this resistance area depending entirely upon the specific resistance of the soil. In the design of a multi-plate earth system, the electrodes should be so spaced that the individual resistance areas do not overlap appreciably (see Chapter XIV).

The location of the testing electrode P is not critical provided that it is between points d_1 and d_2, but it is important that the distance between E and C should be sufficiently great to prevent the resistance area of C from merging into that of the main earth plate. If the distance is not sufficient there is no horizontal portion of the resistance curve and hence it is not possible to say how much of the measured resistance is due to the main earth and how much to the temporary current electrode. The adequacy of spacing can be checked by taking measurements with electrode P in several different positions, say, 6 ft apart. The spacing is correct if the reading obtained in each case is substantially the same.

The voltmeter-ammeter method just described is not very reliable when accurate results are required due to the possible presence of earth currents and the effects of electrolytic back e.m.f. A rough determination can be made by reversing the battery and averaging the readings, but it is preferable to use a specially designed earth tester whenever possible.

The "Megger" Earth Tester. The "Megger" earth tester is similar in appearance to the Megger insulation tester (Fig. 663), and has the same type of moving system (potential and current coils). It operates on the fall of potential method described above, but the current through the earth resistance is reversed at a rapid rate to eliminate

the effects of electrolytic B.E.M.F. and extraneous earth currents. The generator produces a direct current but a rotary reverser mounted on the generator shaft produces the required alternating test current. The ohmmeter part of the instrument is of the moving coil type which will operate only on direct current. The alternating potentials picked up by the pressure electrode are therefore converted back to d.c. by means of a synchronized mechanical rectifier. The circuit arrangements are shown in Fig. 670. Terminals C_1 and P_1 are normally strapped and are on some instruments combined as one terminal marked "E." It is possible by disconnecting this strap to use the instrument for measuring the Specific Resistance of the soil.

The "fall of potential" method of measuring the resistance of an earth system may not be practicable in a congested space. If a water main or other good earth connexion is available, terminals P_2 and C_2 should be linked and connected to the known good earth. By connecting terminals P_1 and C_1 to the earth under test, measurements can be made of the actual resistance between the two earth systems. Care should be taken with this method to ensure the the "good" earth is really of low resistance, and that it is outside the "resistance area" of the system under test.

Transmission Testing. There are numerous forms of equipment for testing the transmission efficiency of telephone circuits and apparatus. Most of this equipment is associated with repeater stations and is somewhat outside the scope of this volume. Until comparatively recent years, transmission efficiency tests on subscribers' lines and telephone exchange apparatus were generally of a rough and ready character. There has, however, been a tendency in the last few years to pay more attention to the transmission efficiency of subscribers' lines, exchange apparatus and the shorter junction circuits. This has led to the introduction of several standard transmission testers. Generally speaking, the testers consist of an oscillator which will generate voice-frequency currents at a known volume, and a suitable meter for reading the level of the tone as received at various parts of the circuit.

One common type of tester (Tester No. 109) is made up in the form of a portable unit (some 17 in. × 11 in. × 16 in.) with a separate battery box of somewhat smaller dimensions. The testing set contains a single-valve oscillator which, by means of switching keys, can be made to produce voice-frequency current at 300 c/s, 500 c/s, 800 c/s, 1400 c/s, and 2000 c/s. The power output is controlled by means of a variable feed-back resistance and can be adjusted to a standard power of 1 mW by calibration with the test set meter. The receiving portion of the instrument consists of a valve amplifier, the anode circuit of which is connected to a voltmeter of the moving coil type. The circuit is so arranged that direct readings of the received power (in decibels) are obtained by means of a tapped transformer and a calibrated rheostat. The tester is designed to measure the loss when the

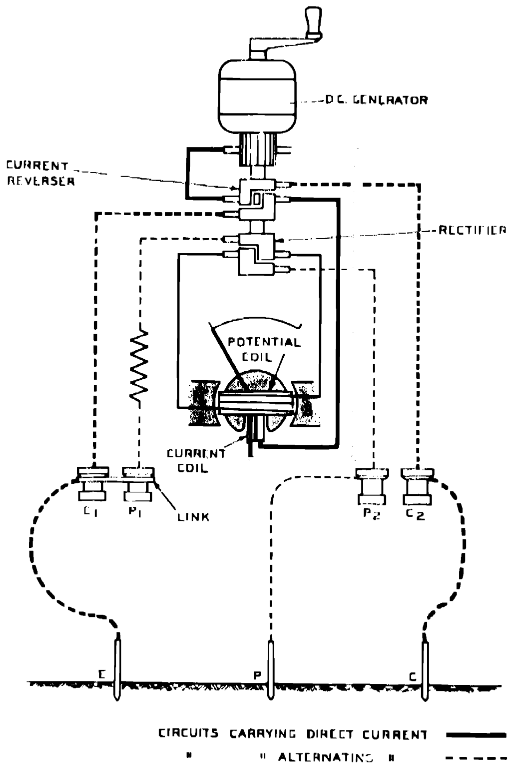


FIG. 670. THE MEGGER EARTH TESTER

circuit under test has an impedance of 600 Ω, but the error is not serious when it is applied to lines which have an impedance which does not differ widely from the standard value.

Another tester (Tester TL 1635) is designed primarily for checking the transmission efficiency of cord circuits and telephone exchange equipment. The apparatus consists of a small portable oscillator (Oscillator No. 8A) with three standard frequencies (300, 800, and 2000 c/s). The receiving instrument is essentially a moving coil voltmeter connected in a bridge metwork of metal rectifiers, and has a range of 0 — 1 V with a minimum error throughout the voice-frequency range. The tester can, if desired, be fed from the exchange power

supply and, with an associated dialling unit, provides a number of facilities for carrying out tests on exchange equipment.

In addition to the main testers, there are several standard oscillators and measuring instruments for use in different circumstances. The measuring

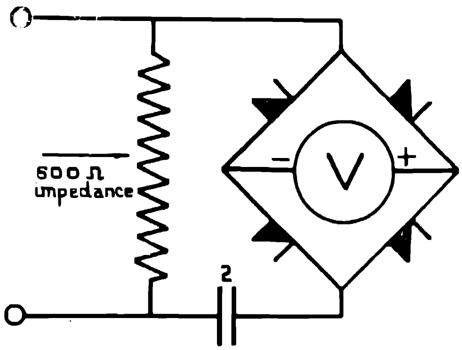


Fig. 671. Circuit of Decibelmeter

instruments are often calibrated in decibels relative to a fixed sending power and are therefore known as a *decibelmeters*. Most decibelmeters are the same in principle, and consist of a sensitive moving coil voltmeter connected across a metal rectifier bridge as shown in Fig. 671. It should be noted that such a meter will only measure the *voltage* across the part of the circuit under test. When the instrument is used for overall transmission efficiency tests, it is necessary to terminate the line with a standard impedance and to obtain this it is usual to include a 600 Ω resistor in the decibelmeter.

Transmission Testing of Subscribers' Lines. The routine transmission testing of subscribers' lines presents some additional problems. In the first place it is not practicable for every faultsman to carry a decibelmeter or oscillator and, even if this were possible, the resulting tests would not check the transmission efficiency of the subscriber's transmitter or receiver. Some years ago a scheme was devised for testing the *sending* efficiency of a subscriber's circuit by the use of a specially designed "noise generator" which was applied by the faultsman to the subscriber's transmitter. A decibelmeter was provided at the exchange and a schedule of permissible readings for each type of subscriber's circuit enabled the testing officer to determine if the transmission was satisfactory or otherwise.

The noise generator was driven by clockwork and was ingeniously designed to give an output which covered the normal frequency range of speech. The scheme did not prove too successful in practice, due to the difficulty of maintaining a constant output from a large number of noise generators, and for this reason the tests have now been discontinued.

Dial Speed Testers. It has already been indicated (Chapter VIII) that, to ensure satisfactory operation of automatic switch mechanisms, the impulse frequency of subscribers' dials must be maintained within the limits of 9 to 11 impulses per second. It is therefore necessary to provide, as part of an exchange testing equipment, a reliable and ready means of checking dial speeds. In one type of dial speed tester a pendulum is employed and the circuit is arranged to count the number of impulses received during the known oscillation time of the pendulum.

The Post Office standard dial speed tester (Figs. 672 and 673) is entirely mechanical and consists of:

(*a*) a clockwork escape mechanism which moves the lower pointer over the scale at a uniform speed;

(*b*) an impulse counting mechanism which is actuated from an electromagnet via a ratchet and pawl system, to move the upper pointer as the impulses are received.

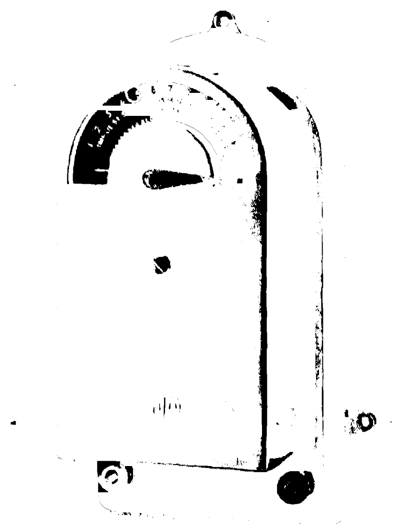


Fig. 672. Dial Speed Tester
(Tester No. 43)

The mechanical arrangements are such that the escape mechanism is released at the beginning of the first impulse and is stopped at the end of the tenth impulse. The distance moved by the lower pointer is therefore a measure of the impulse

frequency, and the scale is calibrated to give a direct reading of the frequency in impulses per second. The upper pointer, which is in the form of a ring, indicates on a separate scale the number of impulses received.

Before a test is made, the instrument is set by rotating the control handle as far as it will go in an anticlockwise direction. This winds up the escape mechanism spring and returns the pointers to their normal position. It is apparent that with this tester ten impulses—no more and no less—are required. If the number sent is other than 10, the escape mechanism is not arrested, and the pointer moves over to the end of the scale. If a reading is not obtained, the cause is indicated by the ring pointer which shows the actual number of impulses received.

Test Desk. Equipment is required at every telephone exchange to facilitate the testing of subscribers' lines, junctions, etc. In the very small exchanges, the equipment usually consists of a small test case mounted on the M.D.F. or the wall of the apparatus room. The test case contains a suitable voltmeter (sometimes a Detector No. 4) and a number of keys for setting up the correct testing conditions. In the larger exchanges, the amount of testing work may be sufficient to occupy fully one or more maintenance officers, and in these circumstances it is usual to provide a *Test Desk*.

Fig. 674 gives a general view of a modern test desk section. The desk follows the same general principles as manual switchboard design, and a suite is built up of single-position sections, each section containing 3 panels. A miscellaneous section of 1 panel (on the right of Fig. 674) is normally provided between each pair of testing positions, so that the circuits terminated on the miscellaneous section are available to the testing officers seated on the adacent testing sections. The centre panel of the test section accommodates a high grade voltmeter and a number of keys by means of which it is possible to set up a wide range of testing conditions. The lower portion of this panel accommodates the supervisory lamps of the various circuits on the test desk. The left- and right-hand panels provide accommodation for the jacks, lamps and keys of the various circuits terminated on the test desk, whilst further accommodation is available in the miscellaneous section. The upper portions of the panels are provided with compartments for the accommodation of fault cards, dockets, etc.

The equipment of the test desk varies slightly with the use to which the position is put. In the smaller exchanges no differentiation is made between the test desk positions, but in the larger installations, it is common practice to set aside one test position for junction testing, a number of positions for the testing of subscribers' lines, and one or more positions for the tests necessary in connexion with new installation work.

Provision is made for the following main circuits which are equipped as required:

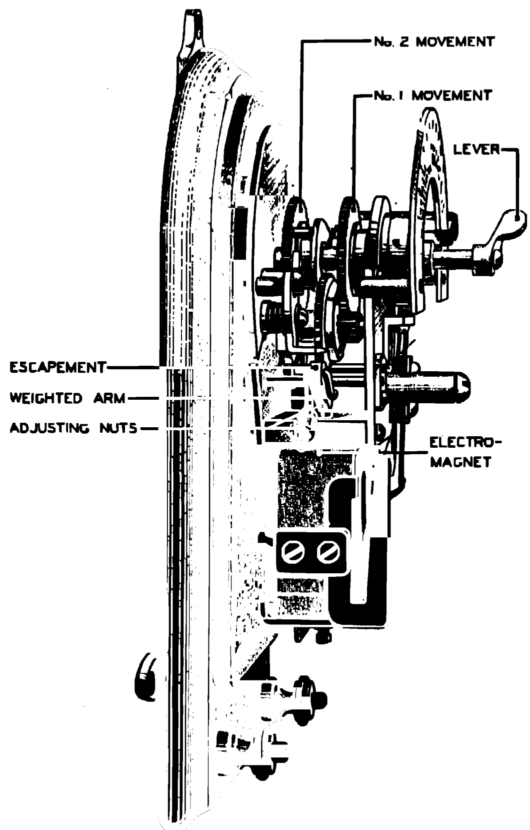


FIG. 673. MECHANISM OF DIAL SPEED TESTER

(*a*) *A test cord*, which is associated with the keys and voltmeter of the position (described later).

(*b*) *A sounder cord*, which enables a telegraph sounder to be connected to a line, thereby giving an audible indication as the circuit is proved from point to point.

(*c*) *An interrupted earth plug*, by means of which it is possible to apply interrupted earth (0·75 sec on, 0·75 sec off) to the line conductors for identification purposes.

(*d*) *A speaking cord*, which enables the test clerk to speak, dial and ring on any line terminated on the test desk.

(e) *A connecting cord* circuit, which enables any line to be extended as required. This cord circuit has a number of keys associated with it so that the test clerk can speak or monitor on the connexion, can dial or ring in either direction, or can hold the call.

(f) *A ringing cord*, by means of which it is possible to supply ringing current to external

that both the line and exchange equipment can be tested separately.

(i) *Test and plugging-up circuits* for faulty subscribers' lines.

(j) *Testing circuits* for lines under construction

(k) *Incoming circuits*, by means of which telephonists, faultsmen, fitting staff, etc., can obtain the attention of the test clerk.

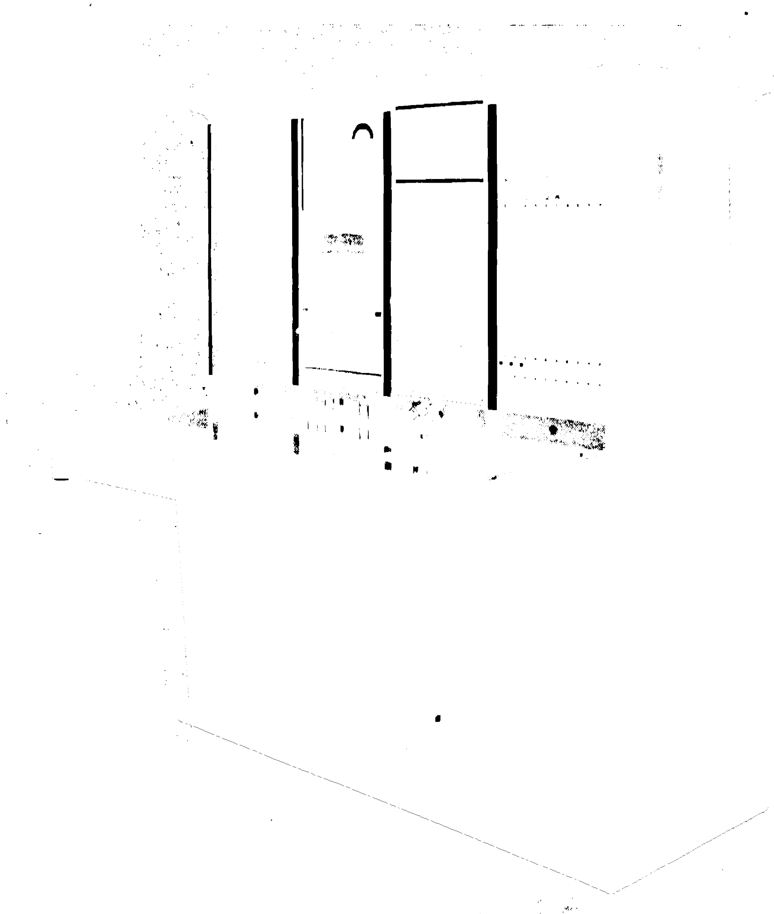


FIG. 674. TEST DESK SECTION OF MODERN DESIGN
(Note miscellaneous section on right)

maintenance officers for the testing of subscribers' bells, etc. This cord circuit provides for automatic tripping of the ringing, and there is also a key to reverse the connexions of the ringing to line.

(g) *Test extension lines* to the manual switchboard for obtaining access to circuits terminated on the manual board.

(h) *Test interception circuits* to the M.D.F. so

(l) *Outgoing circuits* to the exchange equipment as required.

In addition to the above, there are many other circuits of a miscellaneous character.

A *test rack* is provided in the smaller exchanges which do not justify the expense of a complete test desk. The test rack is built up from a standard 2 ft 6 in. apparatus rack with a simple shelf for the accommodation of the test plugs,

etc. The test rack is self-contained in that it accommodates all the various relays, etc., associated with the testing and miscellaneous circuits.

Test Jack Frame. At all except the smaller exchanges it is usual to provide a *test jack frame*, through which the more important junction circuits

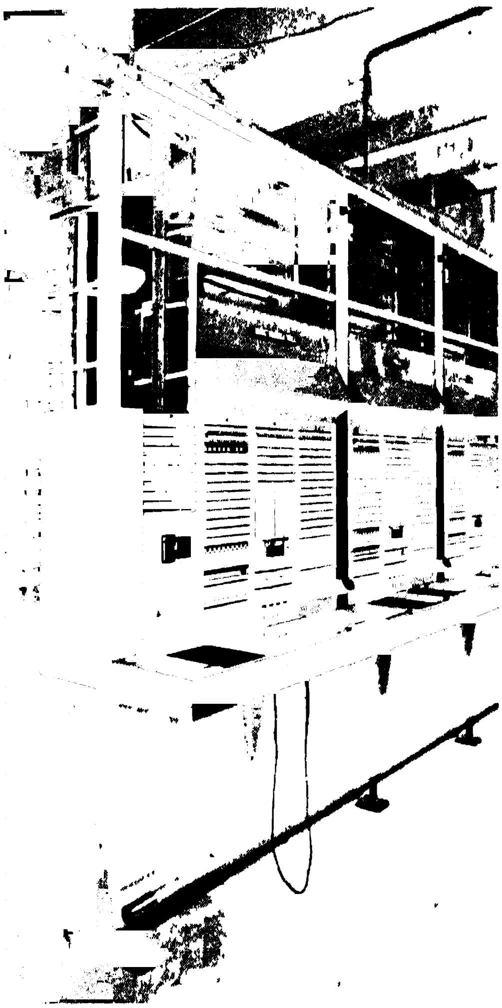


FIG. 675. PORTION OF TRUNK TEST RACK

are passed. Normally the test jack frame is located adjacent to the first position of the test desk so that the test clerk on this position can readily carry out routine and other tests on the junctions. The junctions are routed through break jacks on the test jack frame and a small cord shelf accommodates a number of *patching-out cords* to facilitate temporary changes. Test extension circuits are also provided between the test desk and the test jack frame so that the test clerk can carry out electrical tests from the desk. A dialling circuit is also provided on the test jack frame so that simple functional tests of the junctions can be carried out from the frame.

Trunk Test Racks. At zone centre exchanges it is usual to provide special racks for the testing of trunk and junction circuits. These trunk test racks (Fig. 675) provide similar facilities to the test desk, but have a more extensive jack field through which the incoming and outgoing trunk circuits are taken. A cord canopy is provided above the jack field for the accommodation of patching-out cords, whilst the outgoing trunk circuits are equipped with plunger type keys so that any circuit can be busied whilst tests are in progress

The trunk test rack has the usual testing voltmeter, test cord circuit, and so on, and has a built-in motor driven megger by means of which it is possible to carry out insulation and Varley tests on physical pairs.

The rack is based on an angle iron framework and can be provided either as 4-panel units, 3-panel units, or as single-panel units as required.

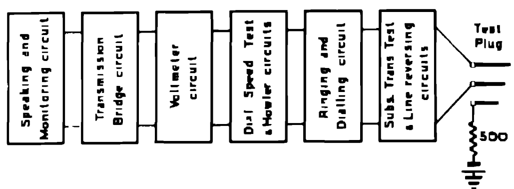


FIG 676 GENERAL ARRANGEMENTS OF TEST CORD CIRCUIT

Test Cord Circuit. The test cord circuit is terminated on a single plug, with which is associated a number of lever type keys, by means of which any desired testing conditions can be set up. It is convenient to consider the complete circuit as six elements in tandem as shown in Fig. 676. In the first element (Fig. 677), the Line Reversing Key (*KR*) gives facilities for changing over the tip and ring connexions, so that reversed conditions can be applied to the testing circuit. The second key of the test cord circuit (*KT*) was used in conjunction with the noise generator (*q.v.*) and the associated decibelmeter for sending efficiency tests of subscribers' instruments. The transmission test circuit provides facilities whereby transmitter feeding current can be supplied from the test cord circuit during transmission tests or, alternatively, a high or low resistance holding loop

can be substituted for cases where the transmitter is fed from some local exchange transmission bridge.

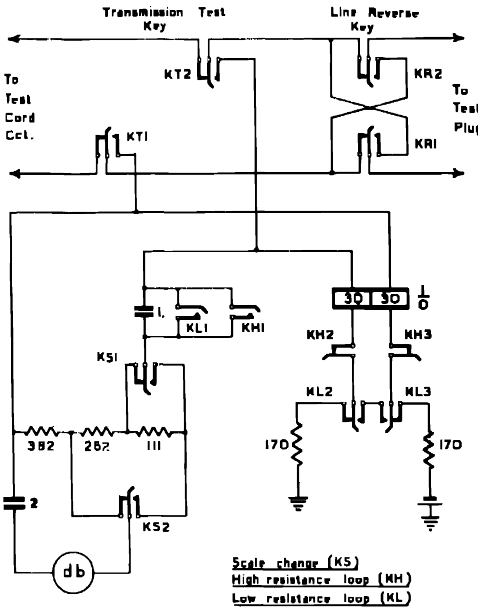


FIG. 677. LINE REVERSING AND TRANSMISSION TEST ELEMENTS

The next element (Fig. 678) shows the dial and ringing circuits. The non-locking Ringing Key (*KX*) applies ringing current to the test plug for

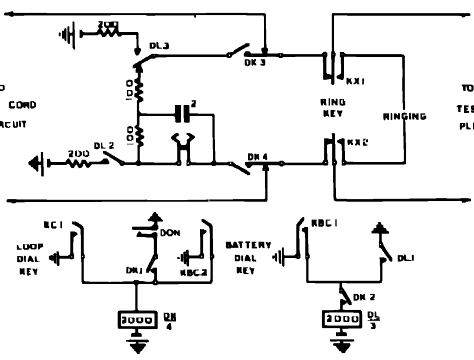


FIG. 678. RINGING AND DIALLING CIRCUIT ELEMENTS

calling a subscriber. The connexions of this ringing can be reversed, if desired, by the simultaneous operation of key *KR* (Fig. 677). The dialling circuit provides for both battery and loop dialling. The operation of the Loop Dial Key (*KC*) operates relay *DK*, which at ***DK*3** and ***DK*4** connects the dial impulse springs to the test circuit. Whilst the dial is off normal, *DK* is held via ***DK*1** in order to prevent interruption of the impulse train should

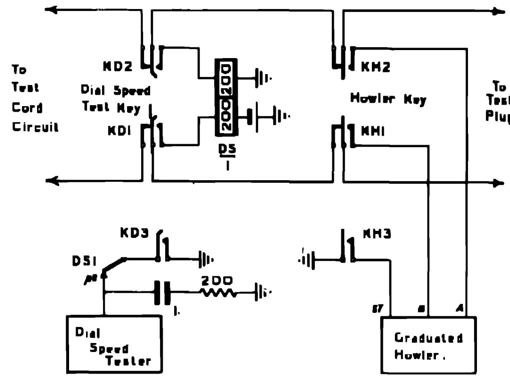


FIG. 679. HOWLER AND DIAL SPEED TEST ELEMENTS

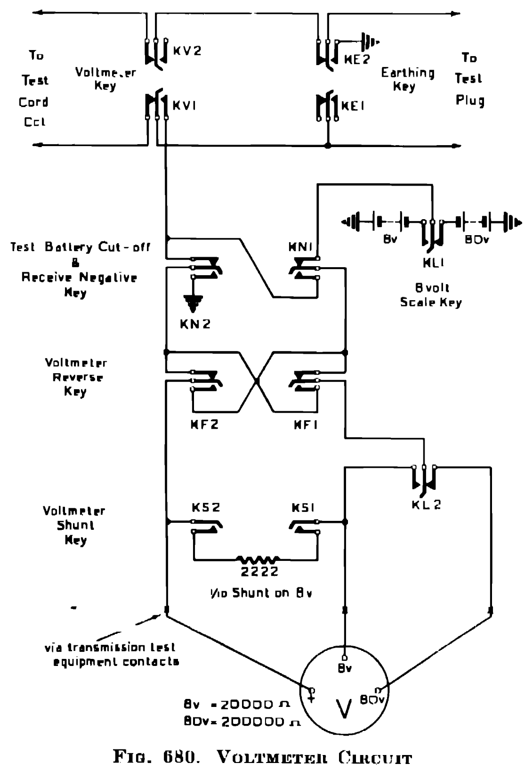


FIG. 680. VOLTMETER CIRCUIT

the Dial Key be restored prematurely. The operation of the Battery Dial Key (*KBC*) operates both *DK* and *DL*. The latter locks to the ***DK*2** contact, and at ***DL*3** and ***DL*2** changes over from loop to battery dialling conditions.

The third element (Fig. 679) shows the circuits

of the Howler Key and of the Dial Speed Test Key. The Howler Key (*KH*) is non-locking, and when operated starts the howler equipment. The howler is, in essence, a mechanical buzzer which generates a loud and piercing note, and is used in various circumstances for obtaining the attention of a subscriber who has left his receiver off the rest. Most modern howler circuits are of the *graduated* type, so that the tone builds up gradually over a period of some seconds in order to avoid acoustic shocks to any subscriber who may be listening.

The operation of the Dial Speed Test Key (*KD*) connects an impulse accepting relay (*DS*) to the loop. Contact ***DS*1** repeats the impulses received from the subscriber's dial to the mechanical dial speed tester fitted on the test position (see Figs. 672 and 673).

The voltmeter circuit (Fig. 680) comprises six keys which, together with the Line Reversing Key, give facilities for a very wide range of d.c. tests. The use of the various keys is illustrated in the schedule given below of the more important tests.

To Test For	Wire	Keys operated
Earth or low insulation	*B* *A*	*KV* *KV* and *KR*
Wire to wire insulation	*B* *A*	*KV* and *KE* *KV*, *KE*, and *KR*
Resistance of single wire earthed at distant end	*B* *A*	*KV* *KV* and *KR*
Resistance of pair looped at distant end or disconnexion test	*A*/*B*	*KV* and *KE*
Receive negative current	*B* *A*	*KV* and *KN* *KV*, *KN*, and *KR*
Receive positive current	*B* *A*	*KV*, *KN*, and *KF* *KV*, *KN*, *KF*, and *KR*
Presence of condenser	*A*/*B*	*KV*, *KE*, *KR* on and off

The deflection of the voltmeter in each case gives a general indication of the test results, and a testing officer can, with a little experience, detect the presence of fault conditions from the voltmeter reading. Where the actual resistance value is required, it can readily be obtained from a chart which gives the relationship between the voltmeter reading and the circuit resistance. On a modern test desk the chart (which is on similar lines to Table X) takes the form of a sliding tray, which is accommodated in the test panel. The Voltmeter Shunt Key (*KS*) and the 8 V Scale Key (*KL*) may be used in conjunction with the other keys where it is difficult to obtain an accurate reading on the normal scale. Generally speaking, the high voltage (80 V) test battery is used for insulation tests where the resistance to be measured exceeds about 45 000 Ω. The low voltage (8 V) is employed for resistance values between 4500 and 45 000 Ω, whilst the 8 V scale and shunt is best for resistances below 4500 Ω.

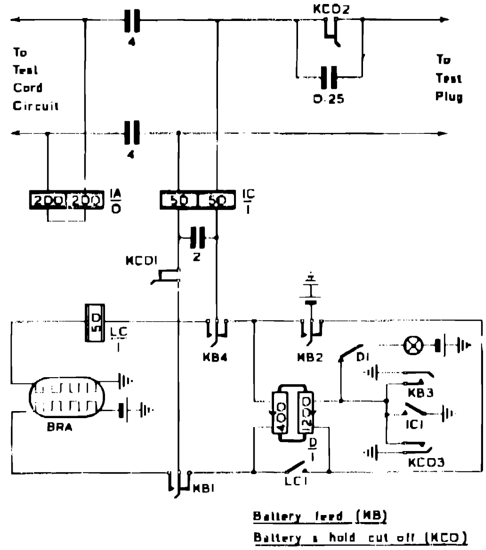


FIG. 681. TRANSMISSION BRIDGE OF TEST CORD CIRCUIT

The transmission bridge element of the test cord circuit is shown in Fig. 681. Ordinarily the 400 Ω winding of relay *D* is applied to the loop via *IC* to receive the supervisory signal. *IC* operates to the loop current and at ***IC*1** energizes the polarizing winding of *D*. ***IC*1** also lights the supervisory lamp. When the call is answered, the reversal of line current operates relay *D* which, at ***D*1**, extinguishes the lamp. When a connexion is made direct to a subscriber's line, a transmission bridge is provided from the ballast resistor (*BRA*) via *LC* and *IC* by the operation of the Battery Feed Key (*KB*). The shunt field relay *D* is now in a local circuit and is operated by contact ***IC*1** for so long as the loop persists. A supervisory signal is given by the release of contact *D*1 as before.

The test desk telephone circuit is connected to the test cord by the operation of the Speaking Key (*KK*) as shown in Fig. 682. The circuit is

of normal design with anti-sidetone arrangements and rectifiers across the receiver to prevent acoustic shock. The operation of the Transmitter Cut Out Key (*KZ*) disconnects the test cord and the receiver from the regular induction coil, and inserts a special high impedance coil to minimize the tapping loss during monitoring.

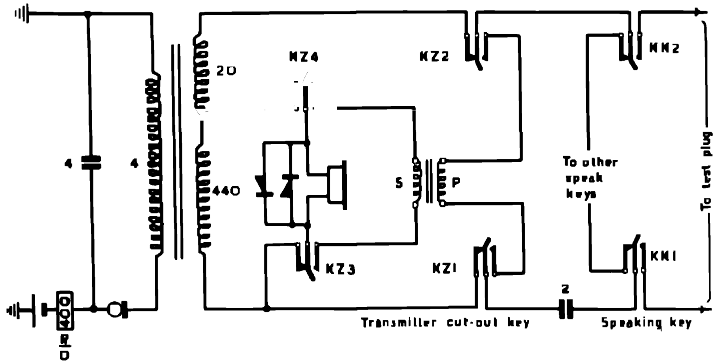


FIG. 682. SPEAKING AND MONITORING ELEMENT OF TEST CORD CIRCUIT

Fig. 683 shows the additional equipment required in the test cord circuit when it is necessary for the test clerk to carry out tests via test extension equipment to a sleeve control manual switchboard. When it is desired to make such a test, the test extension key (*KTX*) is operated to change the test circuit to sleeve control conditions. Relay *TA* operates to the earth from the sleeve of the line terminating relay set and at ***TA*1** operates relay *TB* and causes the "sleeve continuity" lamp to glow. *TB* in operating disconnects the bridge control supervisory circuit at ***TB*1** and ***TB*2** (see also Fig. 681), and at ***TB*3** changes over the dialling circuit from bridge control to sleeve control dialling conditions. Relay *DC* operates (via ***TB*3**) when the loop dial key is thrown, and at ***DC*1** removes the short circuit from the 3000 Ω resistor in the sleeve circuit to prevent the operation of relay *LR* in the line termination (see Fig. 532). Contacts ***DC*3** and ***DC*4** connect battery to the *A* and *B* wires through impedance *I* to operate the switching relay in the sleeve control relay set. Relay *FA* operates when the sleeve current increases under the supervisory condition, and at ***FA*1** lights the test circuit supervisory lamp (not shown in Fig. 683).

Minor Transmission Testing Equipment. Figs. 684 and 685 give simplified circuits of the equipment designed for "minor" transmission testing at exchange test desks. The oscillator (Fig. 684 is a straightforward triode circuit with a tuned grid circuit. The oscillations are derived from the tuned circuit comprising the inductance *L* and the condenser *C*, the oscillations being maintained by feeding back to the grid circuit a proportion of the output via a third winding of the transformer *T*2. The frequency of oscillation is adjusted initially by tappings on *L*. The a.c. output from the triode is passed via transformer *T*1 to the neon lamp which limits the output to a value slightly above its striking voltage (about 110 V). To obtain the high voltage necessary to operate the neon lamp, *T*1 is a large ratio step-up transformer, and subsequent reduction of voltage is arranged by a corresponding step down ratio at *T*2.

The value of feed back to the oscillatory circuit is adjusted by means of resistor *YR* so that the neon lamp just strikes. As the out-

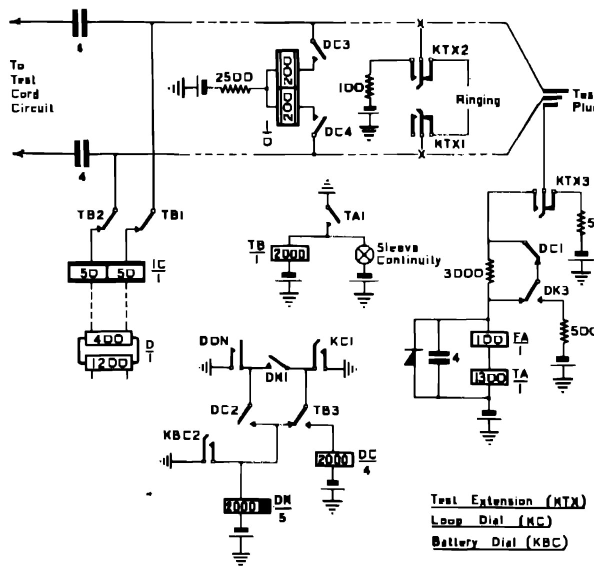


FIG. 683. MODIFICATIONS TO TEST CORD CIRCUIT AT EXCHANGES WITH SLEEVE CONTROL MANUAL BOARD

put voltage rises during the first half wave, the neon lamp strikes at a critical value and the resultant current flow prevents any further rise of voltage. When the voltage falls, the neon lamp is extinguished and the process is repeated during each succeeding half wave. The striking voltage of a neon lamp varies slightly with the polarity

of the applied e.m.f. and condenser *QA* is provided to prevent the partial rectification which would otherwise occur. The condenser is charged by each successive half cycle of current through the neon lamp and after each half cycle remains charged in such a direction as to assist the following half wave to strike the lamp. After a few cycles, the charge on the condenser is such that the neon lamp strikes when the applied voltage is equal to the *mean* striking voltage of the positive and negative half waves, i.e. the lamp behaves as if its striking voltage were the same in either direction.

In addition to the neon lamp control, the circuit is arranged so that an increase of current in the neon lamp circuit increases the grid bias of the valve and so reduces the amplification. The normal grid bias is obtained by the voltage drop in the 400 Ω cathode resistance. The additional control bias is built up by the voltage drop across resistor *YA*.

The oscillator is mains operated and has 4 output jacks arranged in parallel. There are two 300 Ω resistances in the leads to each jack, and the load is maintained as constant as possible by the 600 Ω terminal impedance connected to the inner springs of the jacks. The oscillatory frequency is usually 800 c/s, but separate oscillators of 300, 500, 1400, and 2000 c/s may also be provided if required.

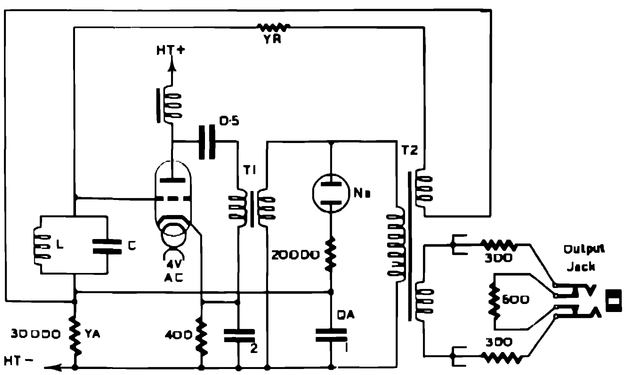


FIG. 684. CONSTANT OUTPUT OSCILLATOR FOR MINOR TRANSMISSION TESTING

The amplifier and decibelmeter circuit (Fig. 685) consists of two pentodes in tandem. The a.c. output from the second pentode is applied via metal rectifiers to two 4μF condensers which are thus charged to the voltage of the positive and negative half cycles received. The test desk voltmeter is connected across both condensers so that the voltage applied to the meter is the sum of the condenser voltages. The voltmeter has an additional scale calibrated in decibels to give a direct reading. The zero of the decibelmeter is adjusted before commencing tests by means of a standard 1 mW tone, and the 60 Ω potentiometer in the cathode circuit of the second valve. This potentiometer varies the negative feed-back voltage applied to the grid circuit of the first valve and so

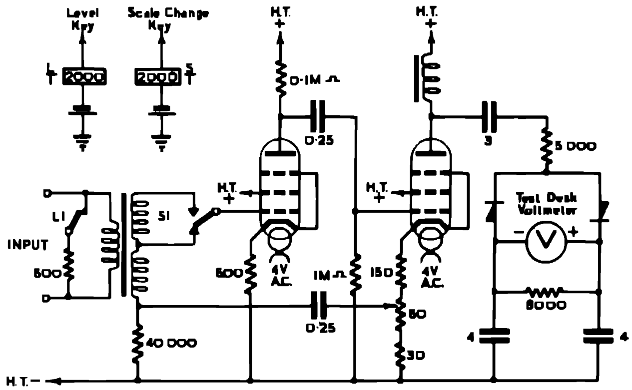


FIG. 685. AMPLIFIER CIRCUIT OF MINOR TRANSMISSION TESTING EQUIPMENT

corrects the total amplification of the unit. Keys in the test cord circuit control relays *L* and *S* Relay *S*, by changing over the tapping on the input transformer changes the range of the decibel meter scale. Ordinarily, there is a 600 Ω terminal impedance on the input side of the amplifier If it is desired to take a "level" test, e.g. a test at an intermediate point on a through circuit, relay *L* is operated and at *L1* removes the 600 Ω terminal impedance. Fig. 686 shows the switching arrangements for associating the amplifier with the test cord circuit.

Test Interception Circuit. The normal means of obtaining access to a circuit for testing purposes is by means of *Test Interception Circuits* between the test desk and the M.D.F. Special plugs are provided which, when inserted in the standard protector, extend over a 4-wire flexible cord, the external and internal sides of the circuit to a test interception circuit which is multiplied at convenient intervals along the frame. The jacks terminating the interception circuit also appear on the Line side of the M.D.F. so that by the use of clips inserted in the fuse mounting it is possible to test those circuits which do not pass through protectors.

The interception circuit (Fig. 687) not only enables tests to be made of the external circuit

and the exchange equipment but also provides for the continual observation of a circuit with facilities for immediate test should a fault appear. By the use of the "intermediate" jack the testing officer may observe the behaviour of the circuit without in any way interfering with the normal working of

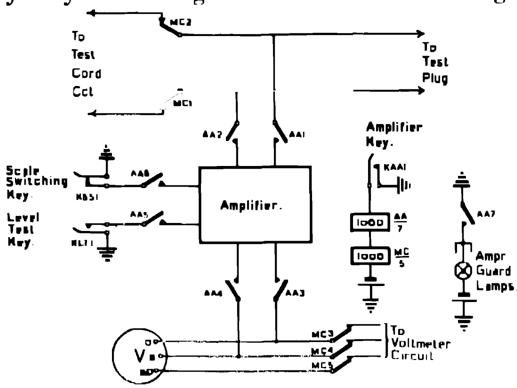


Fig. 686. Association of Minor Transmission Testing Equipment with Test Cord Circuit

the circuit. If he wishes to test the line external to the exchange, the test clerk inserts his test plug in the "Line" jack and obtains direct access to the external cable. At the same time, relay L is connected across the exchange side of the circuit to receive any calling signal from the exchange. Receipt of ringing current operates L which locks until the test plug is withdrawn from the line jack and at $L2$ lights a supervisory lamp. Similarly, when a test plug is inserted in the exchange jack for the testing of the exchange equipment, relay LA and the necessary battery and earth are applied to the external line in readiness to receive the loop calling signal from the subscriber.

Test and Plugging-up Circuit. It is often necessary to disconnect a faulty subscriber's line from the exchange equipment to prevent false calling conditions, etc. It is desirable that the "plugging-up" circuit used for this purpose should be self-restoring when the fault clears. The test and plugging-up circuit shown in Fig. 688 gives a typical arrangement. Jacks are provided on the M.D.F., whereby both the exchange equipment and the subscriber's line can be extended to the plugging-up circuit. Tests can be made by the insertion of a testing plug into the jack on the test desk. Under these conditions relay CO operates to the battery in the sleeve circuit of the test cord, and at **$CO1$** and **$CO6$** applies Number Unobtainable Tone to the subscriber's number within the exchange. **$CO6$** is only required in automatic exchanges where it provides for automatic hunting over a faulty line in a P.B.X. Group. After the line has been tested, keys KA, KB, or KC are operated as follows, depending upon the nature of the fault.

Key Operated	Fault
KA	Earth on B wire. Battery on A wire.
KB	Earth on A wire. Battery on B wire. Short circuit.
KB and KC	Disconnexion.

Whilst an earth or short-circuit fault persists, relay L is held under one or both of its windings due to the fault current. Contact **$L2$** holds relay CO which, in turn, maintains the Number Unobtainable Tone on the subscriber's multiple. **$L1$** operates relay M, which locks via its own contact **$M3$** to the earth at the key contacts. When the

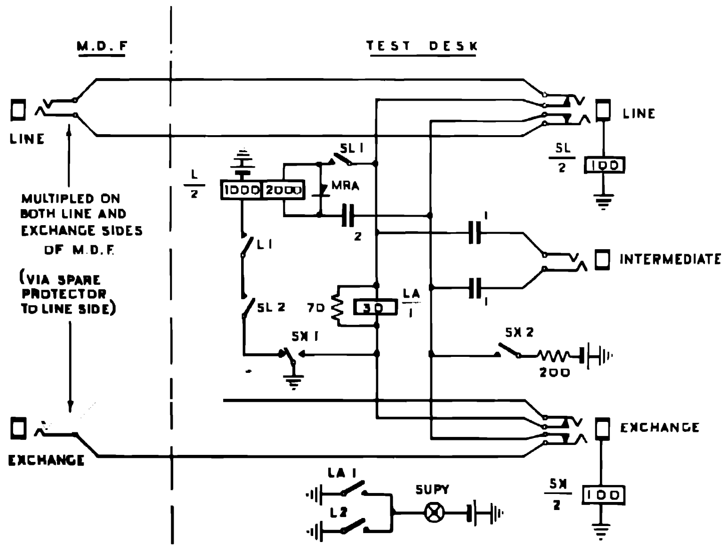


Fig. 687. Test Interception Circuit

fault is cleared, relay L releases and at $L2$ releases CO. Relay M is, however, held as described above, and the restoration of $L2$ completes a circuit for the supervisory lamp. The restoration of $CO1$ and

CO6 restores the line to the exchange equipment and at *CO4* and *CO5* prevents any further re-operation of relay *L* until the *CO* circuit is re-established by the insertion of a testing plug.

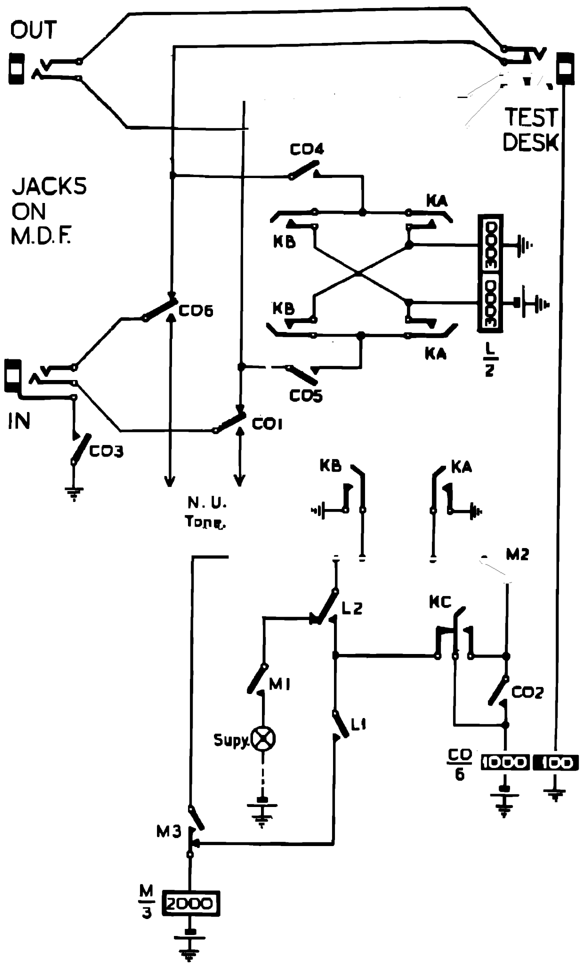


FIG. 688. TEST AND PLUGGING-UP CIRCUIT

If the fault is a disconnexion, both keys *KB* and *KC* are operated. The *CO* relay operates via the *KC* contacts, and locks, independent of the key at contact **CO2**. When the fault is cleared and the external lines are looped, the *L* relay operates and at ***L2*** and ***L1*** completes a circuit for the *M* relay. ***M2***, in turn, disconnects the circuit for the *CO* relay, and the line is switched through at *CO1* and *CO6*. *CO4* and *CO5* release the *L* relay, and a circuit is completed for the supervisory lamp via *L2* and ***M1*** until the keys are restored.

Switchboard Multiple Testers. In a manual exchange it is necessary to carry out periodical tests to ensure that the switchboard multiple is continuous throughout the suite, and that there are no contacts, disconnexions, or reversals. Several testers are in common use to facilitate the initial and subsequent maintenance tests of the multiple circuits.

The tester illustrated in Fig. 689 (Tester No. 24) is designed for rapid continuity tests of an ordinary 3-wire multiple. The tester contains three separate batteries each of two dry cells, together with two

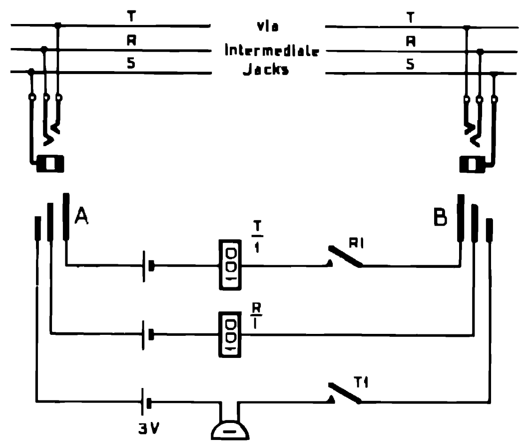


FIG. 689. SWITCHBOARD MULTIPLE CONTINUITY TESTER
(Tester No. 24)

relays and a buzzer. Plug *A* is inserted into the multiple jack of the circuit to be tested, and plug *B* is inserted in some other multiple appearance of the same circuit. If the ring conductor is continuous between these two appearances, then relay *R* operates and at ***R1*** completes a circuit for the tip conductor. If the tip wire is also continuous, then relay *T* operates and at **T1** prepares for the operation of the buzzer. If the sleeve circuit is also satisfactory, then the buzzer operates to indicate that all conditions are correct. This tester is designed to detect a disconnexion in the tip, ring or sleeve conductors of the multiple and also to draw attention to any reversal of the conductors. The non-operation of the buzzer shows that a fault condition exists, but it is necessary to carry out further tests to determine the exact nature of the fault.

Fig. 690 shows the circuit of another useful tester (Tester No. 6) which is extensively used for the location of short-circuit faults in a switchboard multiple. The tester utilizes the potential drop principle already explained in Fig. 641, and has 3 keys (*T*, *R*, and *S*) by means of which the receiver can be associated with the tip, ring or sleeve

conductors of the multiple. Before the test is carried out, it is necessary to ensure that a current of suitable magnitude flows in the circuit in order to produce the requisite potential drop. In most circumstances it is readily possible to arrange for a current to flow through the short circuit or contact fault from the normal earth and battery potentials applied to the circuit under test. Fig. 690 shows the normal conditions in a C.B. Exchange. If there is a contact fault between the tip and ring conductors, current flows from the battery

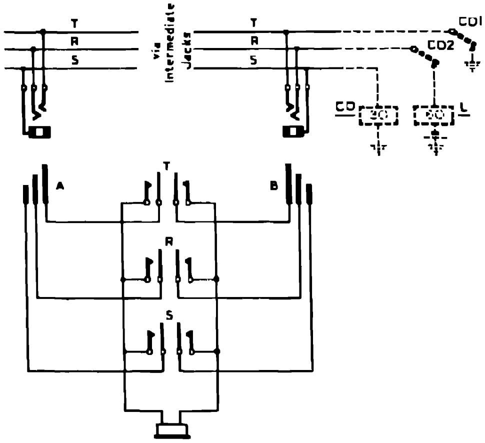


Fig. 690. Tester for Locating Short Circuits in Multiple
(Tester No. 0)

at the line relay to the earth at the *CO* contact on the tip conductor. If plugs *A* and *B* are inserted in consecutive multiple appearances, the potential drop in the wiring between these appearances can be observed by operating key *T* or key *R*. A current through the fault occurs if there is a contact between the ring and sleeve conductors, but no current results from a contact between the tip and sleeve conductors. In these latter circumstances it is necessary to provide a current by artificial means in order to obtain the requisite potential drop. With the arrangement shown in Fig. 690, the conditions can be met by operating keys *T* and R together, thereby applying a battery potential from the *L* relay to the tip conductor for the period of test.

Cord Test Circuits. Switchboard cords are possibly one of the weakest links in a manual switching system. The continual bending of a cord sooner or later breaks the tinsel fibres of the conductor and the intermittent contact of the broken fibres introduces an objectionable scraping noise. Noisy cords may persist for some considerable time before they are located by subscribers' complaints, and to avoid such complaints it is customary to carry out a regular daily routi test of all cords. *Cord test circuits* are provided a regular intervals along the switchboard, and th operator tests all cords by inserting each in tur in the nearest cord test jack and by shaking th cord and listening on the circuit for any noise.

The design of the cord test circuit depends upo the type of cord circuit fitted on a given position. Fig. 691 shows a simple cord test circuit of the type provided on A-positions at C.B. Exchanges. When either a calling or an answering plug is

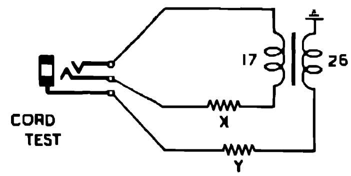


Fig. 691. Cord Test Circuit at C.B. Exchanges

inserted in the cord test jack, direct current from the transmission bridge flows through the 17 Ω winding of the induction coil. Any variation of this direct current due to a variable resistance in the cord, causes a corresponding change of potential across the operator's telephone circuit. The sleeve of the cord test jack is connected to earth

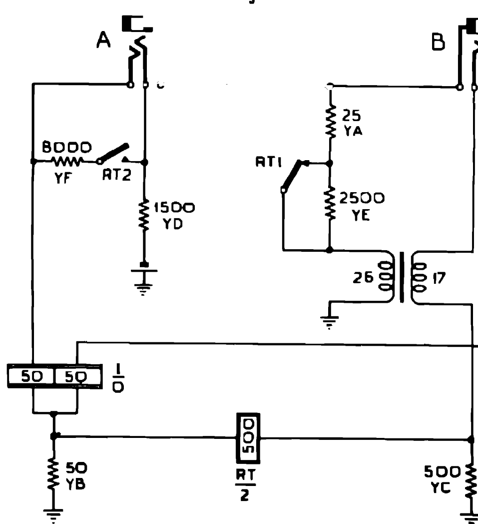


Fig. 692. Cord Test Circuit on Sleeve Control Switchboard

via the 26 Ω winding of the induction coil and, if there is any variation of the current in this circuit (due to a variable resistance of the cord conductors) an alternating e.m.f. is induced into the 17 Ω winding and is heard by the operator. The circuit is so arranged, therefore, that any defect in any of the three conductors is shown up

by the noise transmitted to the listening operator. It is usual to include resistors X and Y in the cord test circuit in order to provide a rough check of the cord circuit supervisory relays and the supervisory lamp circuits respectively. This is, however, a secondary function of the cord test circuit and the resistance values are not chosen to impose strict signalling conditions.

Fig. 692, which is the standard arrangement for all sleeve control exchanges, is somewhat more ambitious than the circuit described above. In addition to the test for continuity and noise on the conductors, the circuit also tests for the correct functioning of the ringing key, and the absence of contacts between or reversal of the tip, ring and sleeve conductors of the cord.

When the answering plug of a pair is inserted into jack A, a circuit is completed for the cord circuit supervisory lamp which lights to the earth at the 26 Ω winding of the induction coil. The calling plug is now inserted into jack B and whilst the plug is partially inserted (i.e. before the ring connexion is established) the calling supervisory lamp glows momentarily to the 51 Ω earth on the sleeve of the cord test circuit. When the plug is fully inserted, relay RT operates from the battery at resistor YD, via the ring conductor of the cord circuit and the 17 Ω winding of the induction coil to the earth at resistor YB. Contact $\boldsymbol{RT1}$ removes the short circuit from the 2500 Ω resistor YE and thereby dims the cord circuit supervisory lamps. Contact $\boldsymbol{RT2}$ applies an 8000 Ω leak across the tip and ring circuit to provide a small direct current in the tip circuit for the "shake test." The cords are tested by the throwing of the operator's speak key, which connects her telephone across the tip and ring conductors of the cord circuit (see Fig. 527). Any variable resistance in the ring conductor of the cords varies the potential difference across the operator's telephone circuit and shows up as a scraping noise in her receiver. Similarly any variable resistance in the sleeve conductor produces a variable current in the 26 Ω winding of the induction coil, which in turn induces an e.m.f. in the 17 Ω winding, so that the noise is audible to the telephonist. Variations of the conductivity of the tip circuit produce a variable potential difference across the 8000 Ω resistor, and hence across the operator's telephone. This change of potential is further augmented by the transformer action of the two windings of the impedance coil I.

After the shake test, the operator throws the "ring answer" or "ring call" key and thereby applies battery via a 100 Ω resistor to the tip conductor of her cord circuit (see Fig. 531). The conditions are now substantially those of a balanced Wheatstone Bridge (Fig. 693) and the RT relay releases. (It will be noted that the 8000 Ω resistor is made sufficiently high to prevent material interference with this balanced condition.) The release of contact $RT1$ reapplies the short circuit

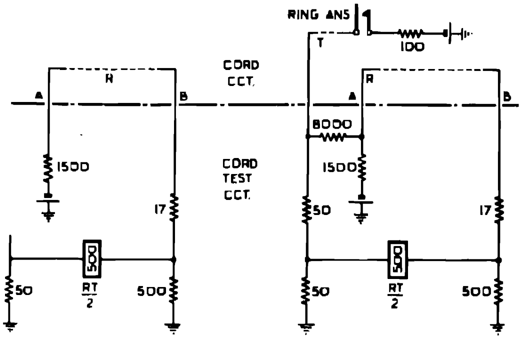


FIG. 693. OPERATE AND RELEASE CIRCUITS FOR RELAY RT (FIG. 692)

to the 2500 Ω resistor YE and allows both supervisory lamps to glow. When the ringing key is released, the bridge is again unbalanced and relay RT operates, thereby dimming both supervisory lamps. Any disconnexion, contact, or reversal of the cord conductors is indicated by irregular operation of the cord circuit supervisory lamps. The following table indicates the result of faults of various types:

Fault	Supervisory Lamp
Tip disconnected	Does not glow on ring key test.
Ring disconnected	Glows when both plugs are inserted.
Sleeve disconnected	Does not glow on first insertion of plug.
Tip and ring in contact	Glows when both plugs are inserted.
Tip and sleeve in contact	Glows when both plugs are inserted.
Ring and sleeve in contact	Does not glow on ring key test.
Tip and ring reversed	Glows when both plugs are inserted.
Tip and sleeve reversed	Glows when both plugs are inserted.
Ring and sleeve reversed	Individual lamps do not glow. Faint glow on calling supervisory lamp when both cords are connected.
100 Ω resistor in ringing key circuit short-circuited	Does not glow on ring key test.

Routine Test of Multiple Answering Equipment. The failure of a lamp signal on a single-appearance answering equipment is quickly observed by the

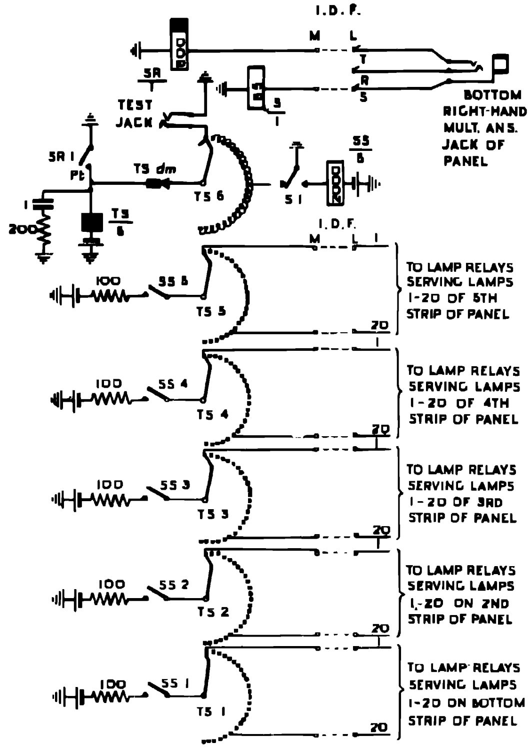


FIG. 694. ROUTINE TEST CIRCUIT FOR MULTIPLE ANSWERING EQUIPMENT
(Sleeve control exchanges)

operating staff. Similarly, the failure of an F.L.S. lamp is soon brought to notice in the normal use of the circuit. With multiple answering equipment, however, the presence of one or more faulty lamps may not become apparent for some considerable time with the resultant loss of operating efficiency. The circuit shown in Fig. 694 has been designed to provide routine test facilities for multiple answering lamps at sleeve control exchanges and is provided at all exchanges with an ultimate of more than nine positions. One 6-level uniselector is required for each panel of a multiple appearance —i.e. a 6-panel answering multiple requires a total of 6 uniselectors. The bottom right-hand jack of each panel is reserved as a test jack. The insertion of any plug in the test jack operates relay *S* from the battery on the sleeve of the cord and *S*, in turn, energizes *SS*. The *SS* contacts apply a 100 Ω battery via the first contacts of uniselector arcs 1–5 to operate the normal lamp relays serving the first calling equipments of each jack strip in the panel. In large exchanges with more than five strips (100 circuits) per panel a second uniselector is required to give the additional arcs. In such cases, additional *S*, *SS*, and *SR* contacts are fitted for the control of the second uniselector.

By momentarily throwing the position "Ring" key, the testing operator may test each calling lamp in turn. Battery from the "Ring" key circuit operates *SR* and ***SR*1** energizes the uniselector magnet. On the release of the Ring key, *SR*1 allows the uniselector to step, the *SR* relay being slugged to ensure an adequate pulse of current to the driving magnet.

Automatic Routiners. There are many more interesting test boxes and routine test circuits designed to facilitate the initial testing of new equipment or the routine testing of plant already in service. Testers in some form or another are, in fact, provided in almost every case where complex functional or electrical tests are required at frequent intervals. The modern tendency is to design testing equipment which is, as far as possible, automatic in action. Such testing devices are known generally as *automatic routiners*. They are of particular application to automatic exchanges, and the main principles of routiner circuit design are described in Vol. II.

EXERCISES XXI

1. Describe the aims of a good maintenance organization, and explain the methods which can be employed to improve the service to the telephone subscriber.

2. Describe a method of measuring the conductor resistance of a subscriber's loop using the apparatus provided for the purpose at an exchange test desk. Explain the principle of the method and mention any precautions that should be taken to ensure a reliable result. (*C. & G. Telephony, Grade I*, 1940.)

3. The effective resistance in the voltmeter circuit of an exchange test desk is 200 000 ohms for the 80-volt scale, and 20 000 ohms for the 8-volt scale; a shunt resistor can also be connected in the latter case to reduce the effective resistance to 2000 ohms. Calculate the value of this shunt resistor. When measuring with this voltmeter the wire-to-wire insulation of a junction line 10 miles long, the actual insulation resistance being 2 megohms per mile, what voltmeter connexions and battery potential would be used, and what deflection would be obtained on the voltmeter? (*C. & G. Telephony, Grade I*, 1946.)

4. Describe the Varley loop test for localizing an earth fault on a line, and explain how the principle is based on that of the Wheatstone bridge.

When localizing an earth fault by the Varley loop test, balance was obtained when all the resistance arms on the bridge were 100 Ω each. If the loop resistance of the line under test was 540 Ω, calculate the distance of the fault from the testing point. Line conductor resistance: 88 Ω per mile loop. (*C. & G. Elem. Telecomms. Practice*, 1947.)

5. Explain the principle of operation of the Megger as used for the direct measurement of insulation resistance. (*C. & G. Telephony, Grade I* 1945.)

6. Give a circuit diagram of the connexions of a Bridge Megger. Show how you would connect up such an instrument for the location of a low insulation fault on one wire of a telephone line.

7. Describe one method of locating a disconnexion on a short unloaded telephone line by means of alternating current tests. Explain the basic principle of the test and indicate what modifications can be made to the testing circuit so that it can be used with accuracy on longer lines.

8. How would you measure the resistance of an exchange earth system? What precautions should be taken in carrying out such tests?

9. Describe the facilities provided by the test cord of an exchange test desk. How does the testing officer verify the presence of the condenser in the subscriber's bell circuit?

10. Describe apparatus suitable for measuring the sending efficiency of a subscriber's circuit, and explain its use. (*C. & G. Transmission and Lines, Grade I*, 1943.)

11. Give a diagram of a circuit which gives facilities for testing and plugging-up faulty lines. Explain how the circuit functions when the line connected to it is (*a*) short-circuit, and (*b*) disconnected.

12. In a certain 40 V C.B. Exchange, the supervisory relays in the A-position cord circuits are required to operate with a minimum line current of 40 mA. The current through the supervisory relay when the tip and ring conductors of the plug are short-circuited is 100 mA. Design a cord test circuit which will not only give an indication of cord conductor faults but will also test the sensitivity of the supervisory relays.

APPENDIX I

CITY AND GUILDS OF LONDON INSTITUTE

Extracts from the REGULATIONS AND SYLLABUSES for Courses and Examinations in

TELECOMMUNICATIONS ENGINEERING

(Reproduced with the kind permission of the City and Guilds of London Institute.)

THE SCHEME for a grouped course in Telecommunications Engineering set forth below has been prepared by the Institute's Advisory Committee and adopted by the Institute. In drafting the scheme, the Advisory Committee have had in mind the needs of employees of the Post Office and of other organizations engaged in the manufacture and operation of telecommunications apparatus.

The former scheme, introduced in 1929, provided separate grouped courses in Telephony, Telegraphy and Radio-Communication, but, in view of the trend of development in telecommunications, it is felt that so sharp a distinction is no longer appropriate. The present scheme provides a course covering the principles and the mathematics, a knowledge of which is regarded as desirable for all branches of telecommunications engineering, and also a selection of specialist subjects introduced into the Second and later years of the course. The present course will enable the student to acquire a sound knowledge of fundamentals and at the same time to specialize in the direction in which his immediate interests lead him.

The course is set forth below as a five-year part-time evening course, requiring attendance for two to two-and-a-half hours an evening for three evenings a week during the normal autumn-winter-spring session. It is hoped, however, that local education authorities will, wherever possible, arrange equivalent part-time day courses. It is considered essential that, throughout the course, laboratory work, providing experimental confirmation of the main principles involved in the subject matter, should be included. The apparatus used should as far as possible be drawn from the telecommunications field.

CURRICULUM OF PRELIMINARY COURSE

(This course, which should be taken by students whose previous education would not enable them to enter profitably upon the First Year of the Course, may extend over one or two years as may be required.)

Mathematics (including Geometry and Mechanics)	Machine Drawing (with especial reference to telecommunications plant and equipment)	Physics (Electricity, Heat, Light and Sound)

It is considered most important that a student shall have had instruction in Machine Drawing before embarking upon the First Year of the Course.

Note. It is intended that the M.K.S. system of units shall eventually be used exclusively in the question papers, but as a transitional measure questions will be framed in both M.K.S. and c.g.s. units, and answers will be admissible in either system.

CURRICULUM OF FIVE-YEAR PART-TIME COURSE

FIRST YEAR

Mathematics for Telecommunications I	Telecommunications (Principles) I	Elementary Telecommunications Practice

SECOND YEAR

Mathematics for Telecommunications II	Telecommunications (Principles) II	Telephone Exchange Systems I *or* Telegraphy I *or* Radio I *or* Line Plant Practice I

	THIRD YEAR	
Mathematics for Telecommunications III	Telecommunications (Principles) III	Telephone Exchange Systems II *or* Telegraphy II *or* Radio II *or* Line Plant Practice II
	FOURTH YEAR	
Mathematics for Telecommunications IV	Telecommunications (Principles) IV	Telephone Exchange Systems III *or* Radio III *or* Line Transmission I
	FIFTH YEAR	
Mathematics for Telecommunications V	Telecommunications (Principles) V	Line Transmission I (if not previously taken) *or* Line Transmission II *or* Radio IV

1. **Examinations.** The City and Guilds of London Institute will hold separate examinations in each of the following—

Telecommunications (Principles) I, II, III, IV and V;
Elementary Telecommunications Practice;
Telephone Exchange Systems I, II and III;
Telegraphy I and II;
Radio I, II, III and IV;
Line Plant Practice I and II;
Line Transmission I and II;
Mathematics for Telecommunications I, II and III

Separate certificates will be awarded to candidates successful in the above-mentioned examinations. Successful candidates will be arranged in two classes (First Class and Second Class) except in Mathematics I, II and III, which will be pass examinations.

No examination will be held by the City and Guilds of London Institute in Mathematics IV or V.

2. **Intermediate Certificate in Telecommunications Engineering (for technical college students).** This Certificate will be awarded upon application to a candidate who is certified by the Principal of a Technical College to have attended satisfactorily the first and second years of an approved course (see 8 below) and to have passed college examinations in Mathematics I and II, and who has passed the Institute's examinations in Telecommunications (Principles) I and II, in Elementary Telecommunications Practice, and in Telephone Exchange Systems I *or* Telegraphy I *or* Line Plant Practice I. The name of the technical college attended will appear on the Certificate.

3.***Intermediate Certificate in Telecommunications Engineering (for external candidates).** This Certificate will be awarded upon application to a candidate who has passed the Institute's examinations in Mathematics for Telecommunications I and II, in Telecommunications (Principles) I and II, in Elementary Telecommunications Practice and in Telephone Exchange Systems I *or* Telegraphy I *or* Radio I *or* Line Plant Practice I.

4. **Final Certificate in Telecommunications Engineering (for technical college students).** This Certificate will be awarded upon application to a candidate who holds an Intermediate Certificate in Telecommunications Engineering (for technical college students), or who has passed the Institute's three Second Year examinations of the Intermediate Course, who is certified by the Principal of a technical college to have attended satisfactorily the third and fourth years of an approved course (see 8 below), and to have passed a college examination in Mathematics III and who has passed the Institute's examinations in Telecommunications (Principles) III and IV and in Telephone Exchange Systems II and III *or* Telegraphy II and Line Transmission I *or* Line Plant Practice II and Line Transmission I *or* Radio II and III. The name of the technical college attended will appear on the Certificate. A candidate who in his course has taken Mathematics IV and passed a college examination therein will have the fact recorded on his Certificate.

5. **Final Certificate in Telecommunications Engineering (for external candidates).** This Certificate will be awarded upon application to a candidate who holds an Intermediate Certificate in Telecommunications Engineering or who has passed the Institute's three Second Year Examinations of the Intermediate Course and who has passed the Institute's examinations in Mathematics for Telecommunications III, in Telecommunications (Prin-

*External candidates applying for the Intermediate Certificate upon the results of the Examinations of 1954 or earlier will be called upon to produce evidence of success in Mathematics II. For 1955 onwards the award will be dependent upon success in Mathematics I and II.

ciples) III and IV and in Telephone Exchange Systems II and III *or* Telegraphy II and Line Transmission I *or* Line Plant Practice II and Line Transmission I *or* Radio II and III.

6. **Full Technological Certificate (for technical college students).** This Certificate will be awarded upon application to a candidate who holds the Final Certificate in Telecommunications Engineering (for technical college students), who is certified by the Principal of a technical college to have attended satisfactorily the fifth year of an approved course (see 8 below), and who has passed the Institute's examinations in Telecommunications (Principles) V and in Line Transmission II *or* Radio IV *or* (if it has not been taken previously) Line Transmission I. The name of the technical college attended will appear on the Certificate. Further, if such a candidate attends satisfactorily a course in, and passes a college examination in, Mathematics for Telecommunications V, this fact will be recorded on the Certificate. The candidate must have attained the age of 21 years at the time of application for the Full Technological Certificate, and have had appropriate experience in the application of his technology.

7. **Full Technological Certificate (for external candidates).** This Certificate will be awarded upon application to a candidate who holds the Final Certificate in Telecommunications Engineering and who has passed the Institute's examinations in Telecommunications (Principles) V and in Line Transmission II *or* Radio IV *or* (if it has not been taken previously) Line Transmission I. The candidate must have attained the age of 21 years at the time of application for the Full Technological Certificate, and have had appropriate experience in the application of his technology.

8. **Approval of Courses.** Applications for the approval of technical college courses in Telecommunications Engineering should be made before October 31st to the City and Guilds of London Institute, upon a form which can be obtained on application. Details will be required of the subjects and classes of instruction included in the course; of the number of hours devoted to each subject and class; of the methods of recording the classwork and homework of the students; of the conditions for entry to the course and for promotion from year to year; and, in subjects where it is appropriate, of the number of hours to be devoted to laboratory work, together with a brief outline of the experiments to be carried out.

9. **Syllabuses.** The syllabuses given below are examination syllabuses. In drawing them up no particular attention has been paid to the order in which the subject will be taught, and the order adopted will depend to some extent upon local circumstances.

10. **Examination Papers.** In setting the various examination papers, the Examiners will assume (*a*) that candidates will have an adequate knowledge of the subject-matter of the earlier years of the course, (*b*) that candidates for Telecommunications (Principles) will have a knowledge of Mathematics adequate for the various stages of the subject and (*c*) that candidates in the specialist subjects will have an adequate knowledge of the earlier stages of the particular subject, and of the appropriate stages of Telecommunications (Principles) and Mathematics.

The M.K.S. system will eventually be adopted throughout the examination papers, but as a transitional measure data will be given first in M.K.S. units, followed by the equivalent c.g.s. units, and candidates' answers will be admitted in either system.

In view of the wide field covered by the syllabuses in Telecommunications (Principles) it has been thought desirable to offer a wider choice of questions in the examination papers than is given normally in the specialist sections. The emphasis in these papers will always be on general principles and basic matters, and teachers should not in any way restrict the attention given to matters of fundamental importance in an attempt to deal with the whole range of topics covered by the syllabus.

11. **Transitional Regulation.** Candidates who began their studies under the former scheme and continue them under the present scheme will be eligible for the award of the Intermediate, Final or Full Technological Certificate in Telecommunications Engineering, as the case may be, provided that their qualifications for the award are substantially equivalent to what is required by the present scheme.

In particular, candidates who have passed the examinations in Technical Electricity Grades I and II and in *two* of the subjects, Telephony Grade I, Telegraphy Grade I and Radio-Communication Grade I, will be awarded the Intermediate Certificate in Telecommunications Engineering (for external candidates) on passing the examination in Mathematics for Telecommunications I and II. Candidates who, under the former scheme, have satisfactorily completed the first two years of an approved course in Telephony, Telegraphy or Radio-Communication, and passed college examinations in Mathematics I and II, will be awarded the Intermediate Certificate in Telecommunications Engineering (for technical college students), if they have passed the examinations in Technical

Electricity Grades I and II and in *one* of the subjects, Telephony Grade I, Telegraphy Grade I, Radio-Communication Grade I (or on passing equivalent examinations in the new scheme).

12. **Exemption from Mathematics for Telecommunications I and II.** Exemption from the examination in Mathematics for Telecommunications I and II will be granted to candidates possessing any of the following qualifications—

(i) A pass in a college examination in Mathematics I and II, forming part of a course approved by the Institute. (ii) An Ordinary National Certificate in Electrical or Mechanical Engineering. (iii) A pass in Mathematics (including Applied Mathematics) as a Principal Subject in a Higher School Certificate examination. (iv) A pass in Pure Mathematics as a Principal Subject in a Higher School Certificate examination, provided that the candidate has also passed in School Certificate Mechanics or Higher School Certificate Mechanics or Applied Mathematics. (v) A pass in Pure Mathematics and Applied Mathematics or Pure Mathematics and Mechanics at Advanced Level in the General Certificate of Education.

13. **Exemption from Mathematics for Telecommunications III.** Exemption from the examination in Mathematics for Telecommunications III will be granted to candidates possessing any of the following qualifications—

(i) A pass in a college examination in Mathematics III, forming part of a course approved by the Institute. (ii) A Higher National Certificate in Electrical or Mechanical Engineering. (iii) A pass in the Intermediate B.Sc. (Engineering) examination of the University of London. (iv) A pass in the Intermediate B.Sc. examination of the University of London, with both Pure and Applied Mathematics.

SYLLABUSES

Note: The syllabuses reproduced in this Volume are those of interest to a student who desires to take the examinations in *Telephone Exchange Systems* or to obtain the *Intermediate or Final Certificates in Telecommunications Engineering* on the basis of the above subject. Detailed syllabuses of the alternative subjects (Radio, Telegraphy, etc. etc.) are contained in the complete Regulations (No. 50) issued by the City and Guilds of London Institute.

PRELIMINARY COURSE

Mathematics for Telecommunications, Preliminary

1. Revision of fractions, decimals, percentages and averages. Significant figures, relation between accuracy of data and accuracy of results. Metric System.

2. Use of algebraic notation to summarize a number of arithmetical calculations or an experimental result. Brackets, negative quantities, positive integral indices. Manipulation of algebraic quantities and simple equations.

3. Proof of laws of indices for positive integral powers. Extension to negative and fractional indices (without proof). Powers of 10: logarithms. Their use in the calculation of expressions met with in telecommunications—e.g. $\frac{1}{2\pi\sqrt{LC}}$.

4. Plotting graphs from given data. Areas of rectangle, triangle, quadrilateral and circle. Volumes of prisms of rectangular, triangular and circular cross-section.

5. Vector addition applied to displacements, velocities and forces. Triangle and polygon of forces; examples involving poles, lines and stays (graphical solutions only). Principle of Moments, application to levers, etc.

Physics, Preliminary

Mechanics

1. Triangle and polygon of forces. Moments and couples. Application to very simple structures (e.g. poles and stay-wires).

2. Work and power. Simple machines. Loss of work by friction. Conversion to heat. Energy and its conservation.

3. Load-extension curve of spring. Load-deflection curve of beam. Elastic stress and strain. Tension and compression. Concept of torsion. Work done in compressing or extending spring.

Heat

4. Heat a form of energy. Sources of heat—the sun, friction, fuel, electric current, etc.

5. Effect of heat on bodies—expansion, change of state.

6. Transmission of heat from one body to another by conduction and radiation; convection. The idea of temperature difference. Thermometers.

7. Quantity of heat. Heat units. Mechanical equivalent. Specific heat.

Sound

8. Nature of sound: production by vibrating bodies; pitch and frequency; transmission by air and other media; velocity; reflection; effect of walls of a room; absorbent materials.

9. Character of speech. The human ear.

Light

10. Light—a form of radiant energy of vibrational character. Velocity affected by media;

relation between frequency and colour; character of white light; transmission of beams and rays in straight lines. Shadows.

11. Reflection, refraction; simple graphical treatment of spherical mirrors and lenses.

Electricity and Magnetism

12. Magnets, forces between magnet poles. The earth's field. Electric charges and forces between charges. Electric current and its magnetic and heating effects.

(Qualitative treatment only of the items included in this section will be required.)

Machine Drawing, Preliminary

It is intended that the work of this course, which may extend over one or two years as may be necessary, shall give the students practice in the making of clear sketches, and in the reading and making of drawings in orthogonal projection of such simple apparatus as they meet with in their duties and their studies. At the same time, an introduction to wiring diagrams and telecommunications circuit-diagram conventions should be included.

The sketches should be made in sketch-books; projected drawings should be made on drawing boards, and the conventions adopted by the British Standards Institution should be followed. A certain proportion of the sketches and drawings should be made from articles handled and measured by the students.

The examples used for the purposes of this instruction should include, in the earliest lessons, a few simple geometrical solids, for the benefit of those students who have no previous experience in geometrical drawing, but the majority of the exercises should be taken from telephone, telegraph and radio practice.

FIRST YEAR

Mathematics for Telecommunications I

1. Revision of indices and logarithms. Logarithm with negative characteristic. The slide rule. The manipulation of simple technical formulae. Factors of $a^2 - b^2$, $a^2 + 2ab + b^2$, $a^2 - 2ab + b^2$. Proportion and variation.

2. Solution of linear equations and linear simultaneous equations with two unknowns.

3. Graphs.

$$y = ax, y = ax + b. \quad y = ax^2, y = a/x.$$

Graphical solution of quadratic and simultaneous linear equations. Simple linear variation (Hooke's Law, Ohm's Law).

4. Angles in degrees. The sine, cosine and tangent of an angle, and their fundamental relations. Values for 0°, 30°, 45°, 60° and 90°. Graphs of sin x, cos x developed from the rotating vector.

5. Ratios for angles greater than 90° and for negative angles. Graph of tan x. Simple problems involving right-angled triangles.

6. Area of segment and sector of a circle. Areas using the trapezoidal rule. Volumes and surface areas of sphere, pyramid and cone. Relations between linear dimensions, areas, volumes and masses of similar bodies.

7. Angle properties of triangles and polygons. Congruence and similarity (simple treatment only). The theorem of Pythagoras; numerical applications. Simple loci. Angle properties of the circle. Tangents, including common tangents.

8. Resolution of forces. Equilibrium of a body under the action of three forces (mainly graphical treatment).

9. Problems on poles, lines and stays. Further problems on moments.

10. Stress, strain, Young's modulus, application to deflection of springs, flat and helical. Concept of ultimate strength in tension, compression and shear.

Telecommunications (Principles) I

1. Electric charge. Elementary concept of electrons and electron flow. Electro-motive force. Electric currents. Conductors and insulators.

2. Ohm's Law. Potential fall round circuit; potential difference. Resistances in series and parallel. Practical units.

3. The magnetic effects produced by currents; force between conductors. Concept of the magnetic field. Permanent magnets; polarity. The earth's field. Soft iron in the magnetic field. Concept of permeability.

4. The motor principle and its application in the moving coil instrument.

5. The generator principle. The induction of an e.m.f. by a changing magnetic field. The induction of an e.m.f. in a conductor moving in a magnetic field.

6. The principle of the induction coil. The e.m.f. of self induction. Lenz's law.

7. Elementary concept of alternating current and alternating voltage. Frequency.

8. The electric field; capacitors; the capacitance of simple systems. The charging current related to changing voltage. The electrostatic voltmeter.

9. Phenomenon of radiation due to alternating currents of high frequency.

10. The heating effect of the electric current; power and energy relations in simple circuits. Units.

11. Electrolysis; Faraday's laws. Simple primary cells. Simple outline of the action of secondary cells.

12. Instruments for the measurement of poten-

tial difference and current (moving coil, moving iron and hot wire).

13. Use of shunts and multipliers. The simple potentiometer, and its application for measuring current. The Wheatstone bridge.

14. The nature of sound. Means of controlling the flow of electric current by sound waves; the simple microphone. The production of sound waves by electric current. The simple telephone receiver.

Elementary Telecommunications Practice

1. The application of the magnetic effect in relays and simple telegraph instruments.

2. Simple circuits for Morse signalling. Signalling codes. Application of Ohm's law in simple signalling circuits. Simple ohm-meters employing battery and milliammeter.

3. Application of the heating effect; lamps, heat coils and fuses. Dissipation of heat by conduction, convection and radiation. Power rating of coils and resistors.

4. The simple telephone circuit. The carbon microphone. The telephone receiver.

5. Current variation in simple circuit due to variation of resistance. Function of the d.c. and a.c. components of current in the telephone circuit. The induction coil. Need for polarization of the receiver. Moving coil microphones and receivers.

6. Description of the simplest forms of d.c. motor and generator. Function of d.c. motor starter.

7. Practical forms of primary and secondary batteries; charging and maintenance.

8. General description of a public telephone system. Provision of plant to meet traffic requirements.

9. Description of typical items of equipment of the manual exchange: plugs, jacks, lamps, relays, keys; resistors, repeating and retardation coils; transformers; capacitors; distribution frames and protective devices, wiring forms and cables. Requirements for reliable electrical contacts; materials. Simple methods of measuring contact pressure.

10. Special features of inductors, capacitors and resistors for radio frequencies. Simple aerial systems.

11. Cables and overhead conductors.

12. Solders, fluxes and soldering.

13. Effects of electrolytic corrosion due to (*a*) leakage and stray currents, and (*b*) use of dissimilar metals in contact.

14. Tests for continuity and identification. Applications of the Wheatstone bridge in testing for continuity and for fault location by the Varley and Murray loop tests. The use of the megger and bridge-megger.

15. An introduction to circuit diagram conventions; standard symbols; detached contact diagrams.

SECOND YEAR

Mathematics for Telecommunications II

Revision of previous work.

1. Solution of quadratic equation in general form by completion of square. Nature of roots of equation. Simultaneous linear equations with three unknowns.

2. Arithmetic and Geometric Progressions. The determination of laws graphically from data for which the relation is of the form $y = ax + b$, $v = ax^2 + b$, or $y = kx^n$.

3. Change of base of logarithms. Graphs of x^n for $n = 2, 1, \frac{1}{2}, -\frac{1}{2}, -1, -2$. Graphical solution of equations including cubics.

4. Solution of triangles by sine and cosine rules. Simple trigonometric equations. Sec, cosec and cotangent of an angle. Radian measure. Ratios of double and half angles. The sum and product formulae. Ratios of small angles.

5. The graphs of wave-forms of the types represented by $\sin(\omega t + \phi)$, $a \cos \omega t + b \sin \omega t$, $a \sin \omega t + b \sin(\omega t + \alpha)$. The graphical addition of a sinusoidal wave-form and its lower order harmonics.

6. Complex quantities of the form $a + jb$: the Argand diagram. Representation of a vector by a complex number and vice versa. Addition and subtraction of complex numbers.

7. Introduction of $\frac{dy}{dx}$ as the limiting value of $\frac{\delta y}{\delta x}$ and as the gradient of a curve. Calculation of $\frac{dy}{dx}$ for $y = ax$ and $y = ax^2$. Graphical determination of $\frac{dy}{dx}$ where $y = a \sin bx$.

8. The velocity/time curve; meaning of its slope and area under it. Motion under constant acceleration or retardation. Energy and momentum.

9. Simple lifting machines: mechanical advantage, efficiency. The relation between weight, tension, sag and span for suspended cables and wires (treated as parabolic).

Telecommunications (Principles) II

1. Conductor and insulator materials. Resistivity. Insulation resistance. Effect of temperature rise on conductor and insulator resistance; temperature coefficient of resistance. Network calculations; Kirchhoff's laws.

2. The electric field, capacitance, energy stored in a charged capacitor. Capacitors in parallel and in series. Simple treatment of growth and decay of

voltage in circuit with resistance and capacitance. Time constant. Capacitance with alternating applied voltage. Capacitive reactance. Electrostatic shielding and capacitance balancing (simple concept).

3. Laws of electromagnetic induction. Mutual inductance, self-inductance. Energy stored in inductors carrying current. Spark quenching.

4. Simple treatment of growth and decay of current in circuit containing inductance and resistance. Time constant. Pure inductance with alternating current. Inductive reactance.

5. The vector representation of alternating currents and voltages. Solution of simple series and parallel circuits containing C, L and R by vector methods. Resonance. Power in the a.c. circuit.

6. The basic principles of simple machines; d.c. generator, motor and a.c. generator.

7. Instruments for the measurement of current voltage and power at power and audio and radio frequencies, including rectifier, thermo-couple and hot wire types. Correct methods of using meters to minimize errors.

8. The composition from fundamental and harmonics of the current wave-forms required for the transmission of vowel sounds. The ranges of frequency required for speech and music transmission.

9. Simple explanation of the independence of action of several e.m.f.'s of different frequencies in the same circuit. Simple concept of the effect of reactive circuits on complex wave-forms, and of frequency distortion.

10. Thermionic emission; the tungsten filament cathode, saturation. The simple diode; space charge, rectifying action. The triode; characteristic curves, valve parameters.

11. Voltage amplifying action for pure resistance anode load (by load line). Concept of non-linear distortion.

12. The metal rectifier; description of properties. The bridge circuit employing metal rectifiers and its application in measuring instruments for audio frequencies.

13. Simple a.c. bridges for the measurement of pure resistance and pure capacitance.

Telephone Exchange Systems I

1. *Subscribers' Apparatus.* Detailed treatment of local battery, central battery and auto telephone instruments. Extension telephone plans; house exchange systems.

2. *Telephone relays;* construction and operating characteristics of telephone relays; slugs and contact assemblies.

3. *Manual exchange systems;* magneto and central battery signalling switchboards, principles and basic circuit operation.

4. *Central battery manual system;* subscribers' line circuit, metering, A-position cord circuits, operators' telephone, engaged test and other functions of the sleeve circuit. Calling rate; busy hour; ratio of day to busy hour calls. Operating methods and times; unit calls; determination of operators' loads.

5. *Junction working;* jack-ended junctions, B-position cord circuits, central battery and generator signalling.

6. *Switchboards.* Lay-out, construction and dimensioning, cabling and equipment of manual switchboards; factors determining switchboard dimensions, keyshelf, multiple, answering jacks and lamps.

7. *Frames and racks.* Main and intermediate distribution frames and apparatus racks; construction and dimensioning, cabling and equipment.

8. *Automatic switching systems;* outline of step-by-step system (non-director); basic two-motion selector and uniselector mechanisms.

9. *Impulsing and stepping;* subscriber's dial, impulsing relay.

10. *Circuit operation* of subscriber's uniselector, 100-outlet group selector, and ordinary final selector.

11. *Trunking.* Simple grading between selectors in non-director independent exchange, cabling scheme and trunk distribution frame.

12. *Power plant;* charge-discharge battery plants; motor-generators, control gear. Efficiencies, voltage drop. Floating of batteries, voltage regulation, private branch exchange power leads. Ringing, tone and pulse supplies.

13. *Test desk;* facilities and principal equipment.

THIRD YEAR

Mathematics for Telecommunications III

Revision of previous work.

1. General solution of the quadratic equation. Maximum and minimum value of a quadratic expression.

2. Binomial theorem in the form $(1 + x)^n$ for positive integral values of n. Its use and limitations when n is negative and/or fractional.

3. Graphs of e^{ax}, e^{-ax}, and $b(1 - e^{-ax})$.

4. Exponential definitions of Hyperbolic Functions and simple relations between them. Solution of $a \cos \theta + b \sin \theta = c$. Analysis of amplitude-modulated wave-form.

5. Expression of complex quantities in the polar form $r\underline{/\phi}$ for multiplication and division, squares and square roots.

6. Differentiation of x^n, $\sin x$, $\cos x$, e^x, $\log_e x$, a^x and of product, quotient and function of a function. Applications to curves and maximum and minimum values of functions.

7. Integration as the reverse process to differentiation. The definite integral as an area. Integrals of x^n, $\sin x$, $\cos x$, e^x and $\frac{1}{x}$ and of similar functions of $(ax + b)$. Mean values. Volumes of revolution.

8. Simple examples of the conservation of momentum, involving impact in one dimension, for elastic and inelastic bodies.

Telecommunications (Principles) III

1. Ferromagnetic materials employed in telecommunications practice; magnetization curves.

2. The magnetic circuit. Effect of air gaps, simple calculations on magnetic circuits. Pull between magnetized surfaces. The hysteresis loss; permanent magnets. Materials for permanent magnets. Magnetic shielding, simple concept.

3. Qualitative treatment of the effects of eddy current. Qualitative treatment of growth and decay of flux in solid cores; effect of short-circuited windings. A.c. magnetization; effect of eddy currents on effective permeability and losses, need for laminations, variation of losses with flux density, frequency, and resistivity and thickness of laminations.

4. Insulating materials employed in telecommunications practice. Dielectric constant; electric strength, energy loss in alternating fields. Loss angle and power factor.

5. A.c. circuit calculations, introduction to the use of complex quantities. Mutual inductance in a.c. circuits.

6. The transformer. Voltage ratio. Magnetizing current. Current ratio on load. Vector diagram on load neglecting leakage reactances. Transformers for power and audio frequencies. Concept of the ideal transformer; equivalent input resistance of a transformer with secondary load.

7. Analysis of behaviour over range of frequency of series and parallel tuned circuits. The Q value. Concept of selectivity. Rejector impedance of parallel circuit. Free oscillation.

8. H.F. resistance, simple concept of skin effect.

9. Electromagnetic shielding (qualitative treatment).

10. Brief qualitative consideration of the radiation of electromagnetic energy by H.F. currents. The simple triode oscillator as an a.c. generator.

11. Amplitude modulation for telegraphy and speech, principle of anode modulation. Expression for sinusoidally amplitude-modulated wave; modulation factor; side bands.

12. The simple diode detector for amplitude-modulated waves. Tetrode and pentode valves; their characteristics and their uses in amplifiers. (Linear regime.) The valve equivalent generator, "constant voltage" and "constant current" forms. Thévenin's theorem.

13. Measurement of valve parameters by static and dynamic methods.

14. Simple pictorial treatment of the propagation of alternating currents along an infinite uniform line of low loss.

15. Concept of velocity of propagation, phase shift per unit length, wavelength, characteristic impedance. Attenuation. Characteristic impedance termination. Balanced and unbalanced transmission systems.

16. Transmission loss. The use of logarithmic units, the decibel and neper. Meaning of insertion loss or gain. Impedance matching for maximum power transfer.

17. The use of transformers in impedance matching.

18. Simple theoretical treatment of typical electromechanical devices employed in telecommunications. Simple electromagnetic analogies, including the effect of mechanical resonances on frequency characteristics; the electro-magnetic sound reproducers, carbon and other microphones. The quartz crystal, its use as a resonator and as a sound reproducer.

19. Photo-electric emission; secondary emission; gas ionisation by collision; fluorescence; the cathode ray tube, photo-electric cell, gas-filled rectifier and relay; the electron multiplier; descriptive treatment.

Telephone Exchange Systems II

1. *Power plant.* Rectifiers, metal, thermionic and mercury arc types; floating-battery charging schemes; automatic voltage control, circuit breakers, smoothing equipment.

2. Emergency and rural conditions; mains failure conditions. Simple prime movers.

3. Determination of required capacities of batteries and charging equipment.

4. Power, tone and pulse distribution; determination of conductor sizes; main and local fusing; alarms.

5. Manual exchange (C.B.), dialling from and to automatic exchanges.

6. *Auto non-director systems.* Line finders, 200-outlet group selectors, 200-outlet final selectors, P.B.X. final selectors.

7. Satellite numbering and trunking schemes; discriminating devices, tandem dialling, junction relay sets, multi-fee metering.

8. Unit automatic exchanges, traffic routing and circuit elements.

9. *Auto director system.* Principles and traffic facilities, trunking scheme.

10. *Auto-manual switchboard.* Facilities and traffic routing; sleeve-control cord circuits and basic line circuits to auto and manual equipment.

11. *Subscribers' apparatus.* Coin box circuits and apparatus. Detailed treatment of anti side tone circuit. Principal features and circuit elements of manual and auto private branch exchanges.

12. *Circuit design considerations.* Timing, margins and factors of safety in design and switching circuits. Principles of signalling over junctions.

13. *Traffic and trunking terms.* Traffic unit; availability; grade of service.

14. *Lay-out* and arrangement of automatic exchanges and associated manual boards, with facilities for "growth."

FOURTH YEAR

Mathematics for Telecommunications IV

Revision of previous work.

1. Proof of the differential of x^n for any index, and of the differentials of the trigonometrical functions.

2. Successive differentiation: Maclaurin's and Taylor's series: series for e^x, $\log_e (l + x)$, $\cos x$, $\sin x$, $(l + x)^n$ for any index. Their use in approximations. Simple introduction to convergency.

3. Further integration; Pappus' theorems; integration by parts, and using partial fractions. Changing the variable and limits of integration. Centroids and moments of inertia.

4. The inverse trigonometrical and hyperbolic functions; principal value; use in integration.

5. Complex functions: powers and roots: de Moivre's theorem. Trigonometrical and hyperbolic functions of complex variables. The exponential form of $r(\cos \theta + j \sin \theta)$: its use in integration and the summation of trigonometrical series. The logarithm of a complex number.

6. Introduction to differential equations. First order differential equations, with variables separable; second order equations $a\frac{d^2y}{dx^2} + b\frac{dy}{dx} + cy = 0$ and $a\frac{d^2y}{dx^2} + b\frac{dy}{dx} + cy = V \sin px$.

7. Simultaneous equations—

$$\frac{dV}{dx} = -zI, \quad \frac{dI}{dx} = -vV.$$

8. Mathematical treatment of π and T networks: characteristic impedance and admittance: attenuation in nepers or decibels. Equivalence of π and T networks. Application to resistive pads and prototype filters.

Telecommunications (Principles) IV

1. More advanced a.c. circuits; admittance, conductance and susceptance; Kirchhoff's Laws; tuned coupled circuits (simple treatment of identical circuits of low loss inductively coupled).

2. The triode oscillator; determination of conditions for oscillation for simple circuits.

3. Triode, tetrode and pentode valves as amplifiers, aperiodic and tuned, under Class B and Class C conditions. Effect of feedback on stability and input impedance. Valves in parallel and in push-pull.

4. The use of valves and other devices in the non-linear regime; modulation; detection and frequency changing. (Simple theory based on square law characteristics.) Amplitude-modulation of the H.F. amplifier.

5. Vector representation of carrier and side-bands. Band-width. Carrier suppression; the balanced modulator, qualitative treatment of valve and metal rectifier types.

6. Demodulation of amplitude-modulated waves. Diode detector, graphical treatment. The super-heterodyne principle in radio reception; multi-electrode frequency changer valves.

7. Automatic gain control; basic circuits.

8. Frequency characteristics, distortion and inter-modulation in amplifiers.

9. The application of negative feedback and the special properties of amplifiers with negative feedback.

10. The mismatched low-loss transmission line. Coefficients of transmission and reflection. Standing waves.

11. The cathode ray tube and the principles of its application in wave-form delineation and in television. Calculation of sensitivity for electrostatic and for magnetic deflection. Simple time-base circuits.

12. Qualitative treatment of electromagnetic radiation from an aerial. The plane electromagnetic wave.

13. The principles determining the polar diagrams of a pair of spaced vertical aerials.

14. The receiving aerial, qualitative treatment except in the case of the frame aerial.

15. Basic types of a.c. bridges for measurement of inductance, capacitance and effective resistance. Various forms of detector.

16. The valve voltmeter and its applications, including Q measurements.

17. Phenomena of hearing. Measurement of sound intensity. The phon. Noise measurement. The psophometer.

Telephone Exchange Systems III

1. Simple mechanical considerations in switches and relays; relation between stiffness of springs and other dimensions. Inertia and vibration effects.

2. *Telephone relays.* Design of magnetic circuit, windings, contacts; a.c. types. Operating characteristics, including times of operation and release; special types. Adjustments; precautions against faults. Spark quench devices.

3. *Automatic switches.* Features of magnetic circuits, mechanical devices, wipers and banks, auxiliary contacts, hardness and wear of materials; impact, friction and lubrication; wiring and jacks. Time study of stepping, hunting and release operations; unguarded intervals.

4. *D.C. impulsing.* Impulsing relays, line and circuit characteristics, current and flux in guarding relays, impulse correction and repetition, special d.c. systems for long lines.

5. *V.F. signalling.* Signalling and dialling. Principles of operation and methods of securing immunity from false operation by speech currents.

6. *Traffic.* Traffic variations, critical study of trunking schemes, applications of the theory of probability. Grade of service.

7. *Trunking.* Design of gradings, traffic recording, routing of traffic, numbering schemes, special services, tandem dialling. Tariffs and methods of charging for telephone service.

8. *Maintenance.* Testing, service observations; methods for the detection, tracing and clearing of faults; elements of automatic routine testers; test and plugging-up circuits.

9. *Long distance.* Trunk exchanges, zone and group centres, application of automatic switching to trunk operations, routing of trunk traffic, signalling and dialling, short-distance trunk and toll circuits; delay operation. Straightforward junction signalling, principal features and circuit elements.

10. Call timing and ticketing, pneumatic tube ticket handling.

11. Auto director system. 1st code and A digit selectors, director, junction relay sets, multi-fee metering.

12. Key sending systems, direct current and voice frequency; circuit elements.

13. Auto systems (other than the step by step). Outline of such systems as the relay, rotary, L. M. Ericsson, cross-bar and motor uniselector systems.

APPENDIX II

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APPENDIX III

ANSWERS TO NUMERICAL EXERCISES

Exercises I

4. 9·54 db.
5. 0·632 dynes/sq. cm.
8. 3·9 per cent.

Exercises IV

3. No. Four 50 Ω resistors in series-parallel formation are required.
11. 62·5 Ω.

Exercises V

2. 1 : 3·16.
6. (*a*) 6 V; (*b*) Voltage across each condenser increases to 16 V.

Exercises VI

1. (*a*) 400 Ω; (*b*) 100 Ω.
2. 78·45 grammes.
5. 6·93 msec.
7. Operate 9·5 msec., release 57·5 msec.
8. Reluctance = 0·2342 Oersted.
(*a*) $L \propto 1/S$; (*b*) $L \propto N^2$.
9. 1·195 H, 3·627 H.
11. It is better to wind additional turns on the relay. Operate lag = 10·95 msec.
12. 17 mA approx.

Exercises VIII

3. Current = 21 mA. Power factor = 0·398.

Exercises XVI

4. When meter key is depressed—
(*a*) Current in 500 Ω meter coil = 59·4 mA;
(*b*) Current in totalling meter = 1·05 A.
When meter contacts close—
(*a*) Current in 500 Ω meter coil = 59 mA;
(*b*) Current in totalling meter = 1·75 A.
10. Power = 35·6 W. Two parallel circuits each with four 12·5 Ω resistors in series, or, four parallel circuits each with two 50 Ω resistors in series.

Exercises XX

4. (*a*) 75 per cent. (*b*) 66·6 per cent.

Exercises XXI

3. Shunt resistor = 2222 Ω.
Deflection = 40 V.
4. 5 miles.
12. 600 Ω between T & R of test circuit.

INDEX